Potential solutions to the energy problem

A talk in honor of Arthur Rosenfeld
Berkeley, CA
April 28, 2006

and International

National Concerns

1) National security which is intimately tied to energy security

2) Economic prosperity

3) The environment

Sustainable, CO_2 neutral energy

Can free-market economies be harnessed to solve the problem?

• Free-markets provide powerful incentives for innovation. (Profit is a very strong motivator)

• Free markets are more nimble than regulated economies.

Question: How many free-market economists does it take to change a light bulb?

Answer: None. If it needed changing, free-market forces would have taken care of it.

Can the free market economic
forces provide a
complete solution
to the energy problem?

The downsides of free-market economies

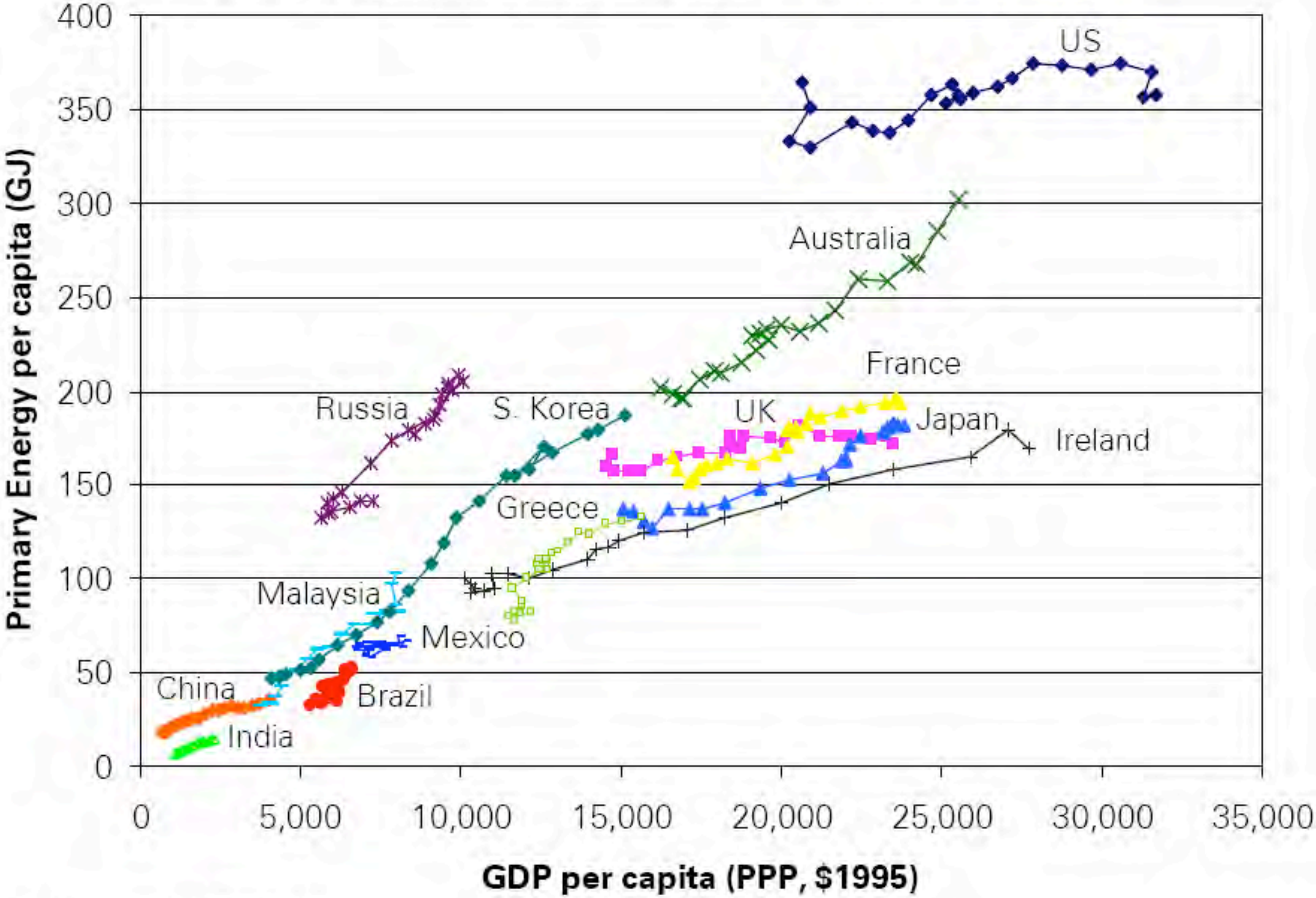
- Free markets do not account for "externalities" (e.g. pollution, climate change.)
- Free market forces promote "local" optimization (e.g. Building contractors have no incentive to invest in operating efficiency.)
- Free markets do not respond to long term problems or international/global issues. (e.g. International fishing, international pollution)

A dual strategy is needed to solve the energy problem:

1) Conservation: maximize energy efficiency and minimize energy use, while insuring economic prosperity

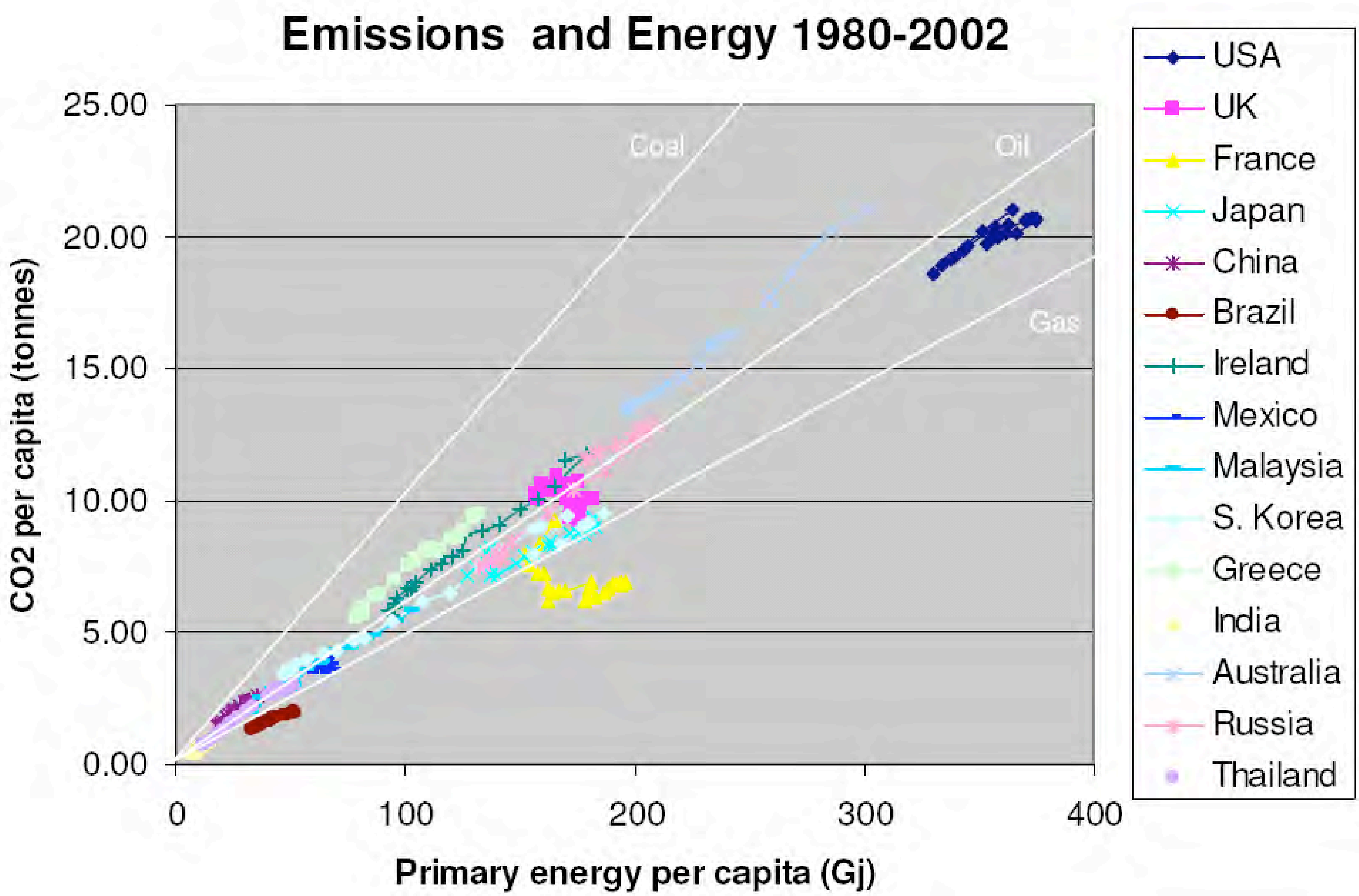
2) Develop new sources of clean energy

Energy demand vs. GDP per capita



Source: UN and DOE EIA

CO_2 emissions depends on the energy source



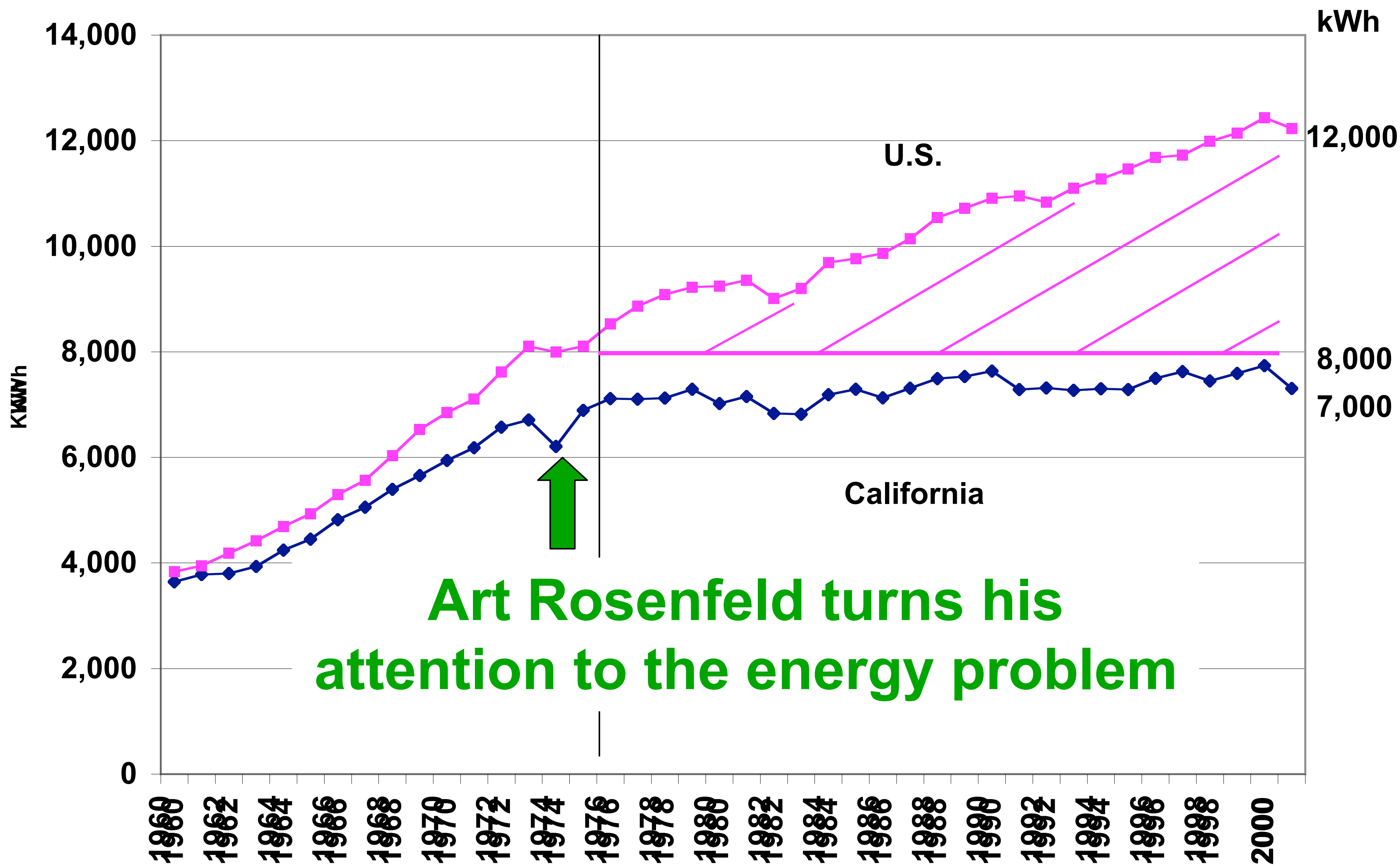
A transition to clean, sustainable energy supplies will require additional regulations to decrease energy waste

And

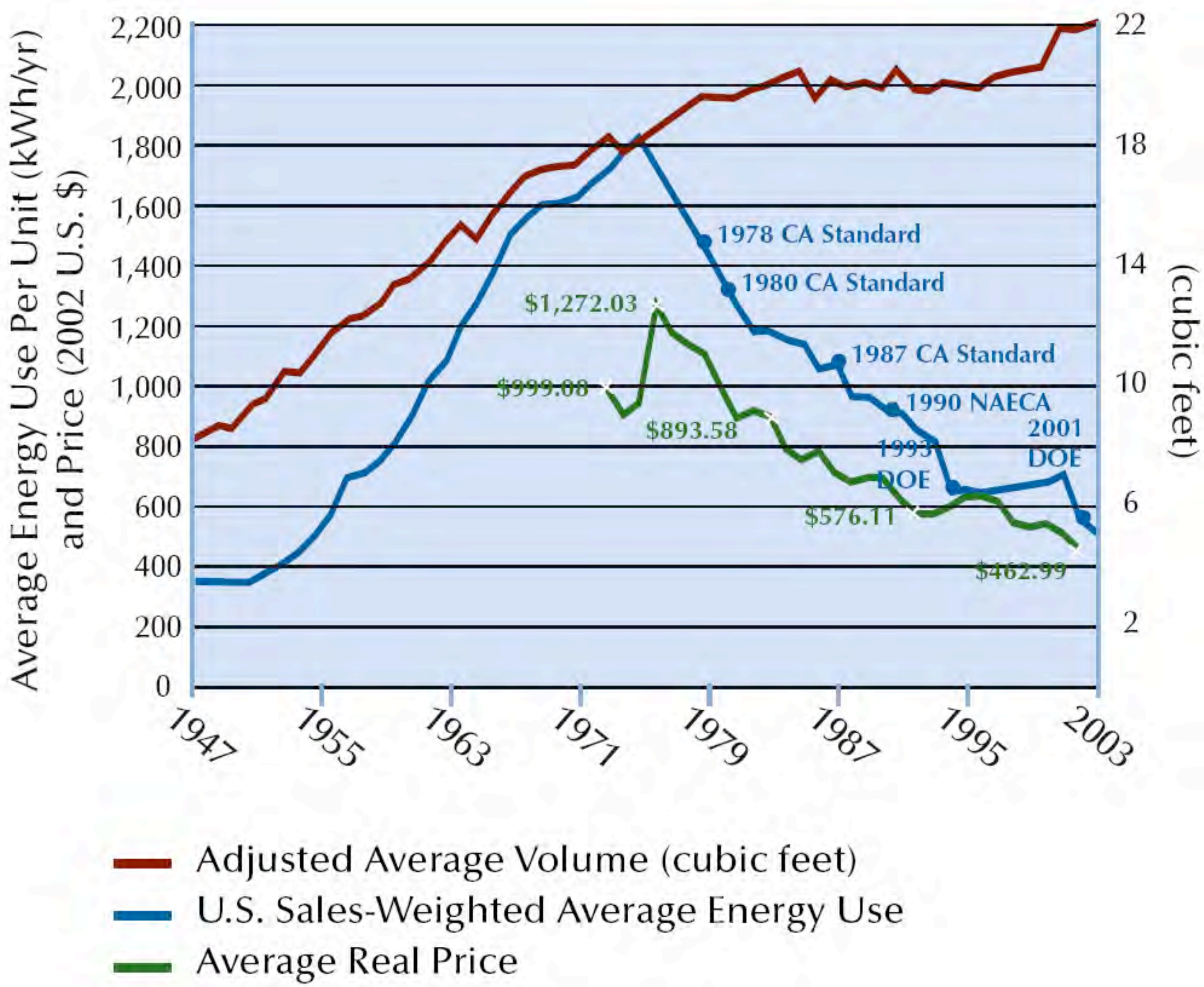
Carbon Cap & Trade (or other mechanism) to account for externalities.

The Demand side of the Energy Solution

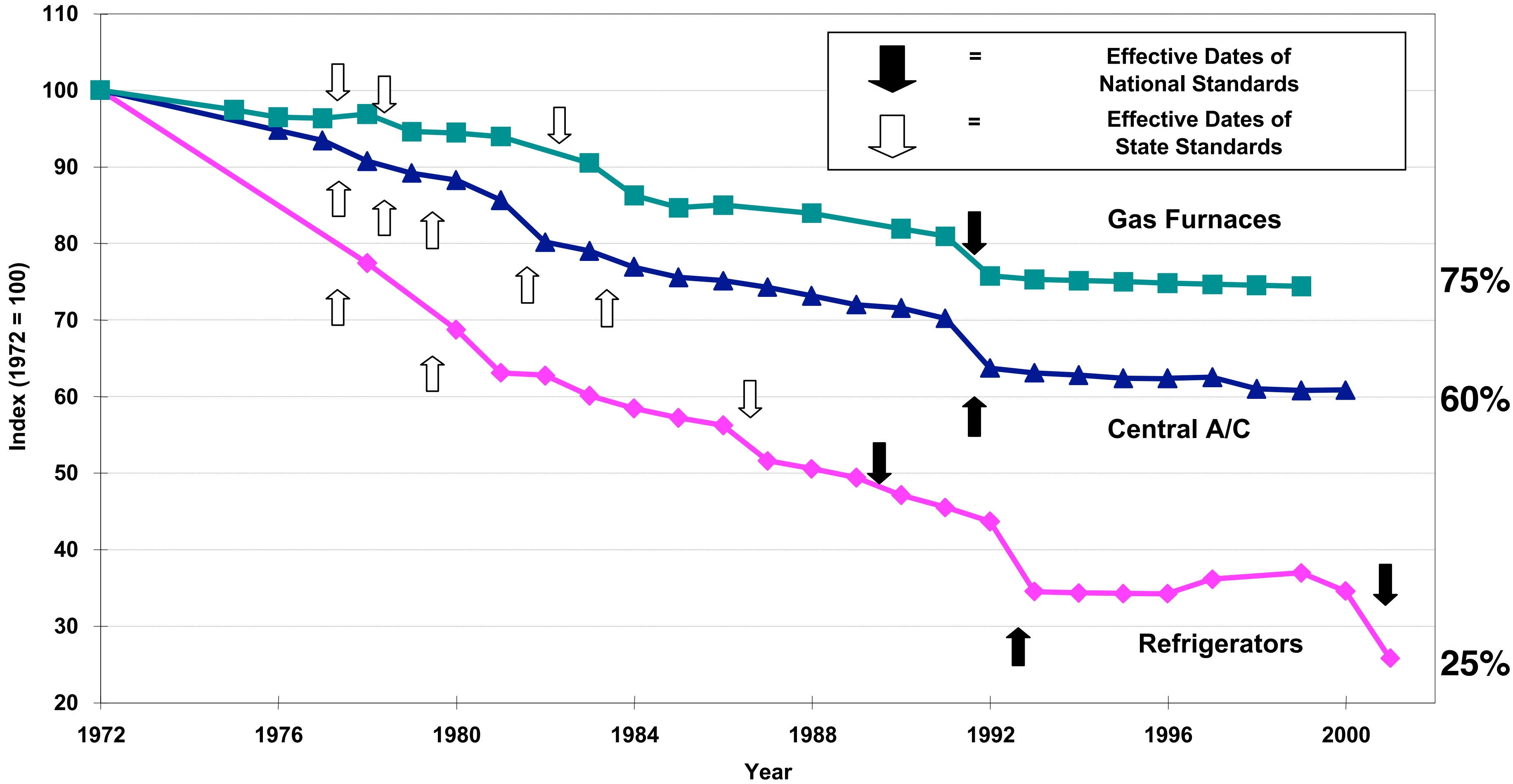
The Rosenfeld Effect ?



Regulation stimulates technology: Refrigerator efficiency standards and performance. The *expectation* of efficiency standards also stimulated industry innovation

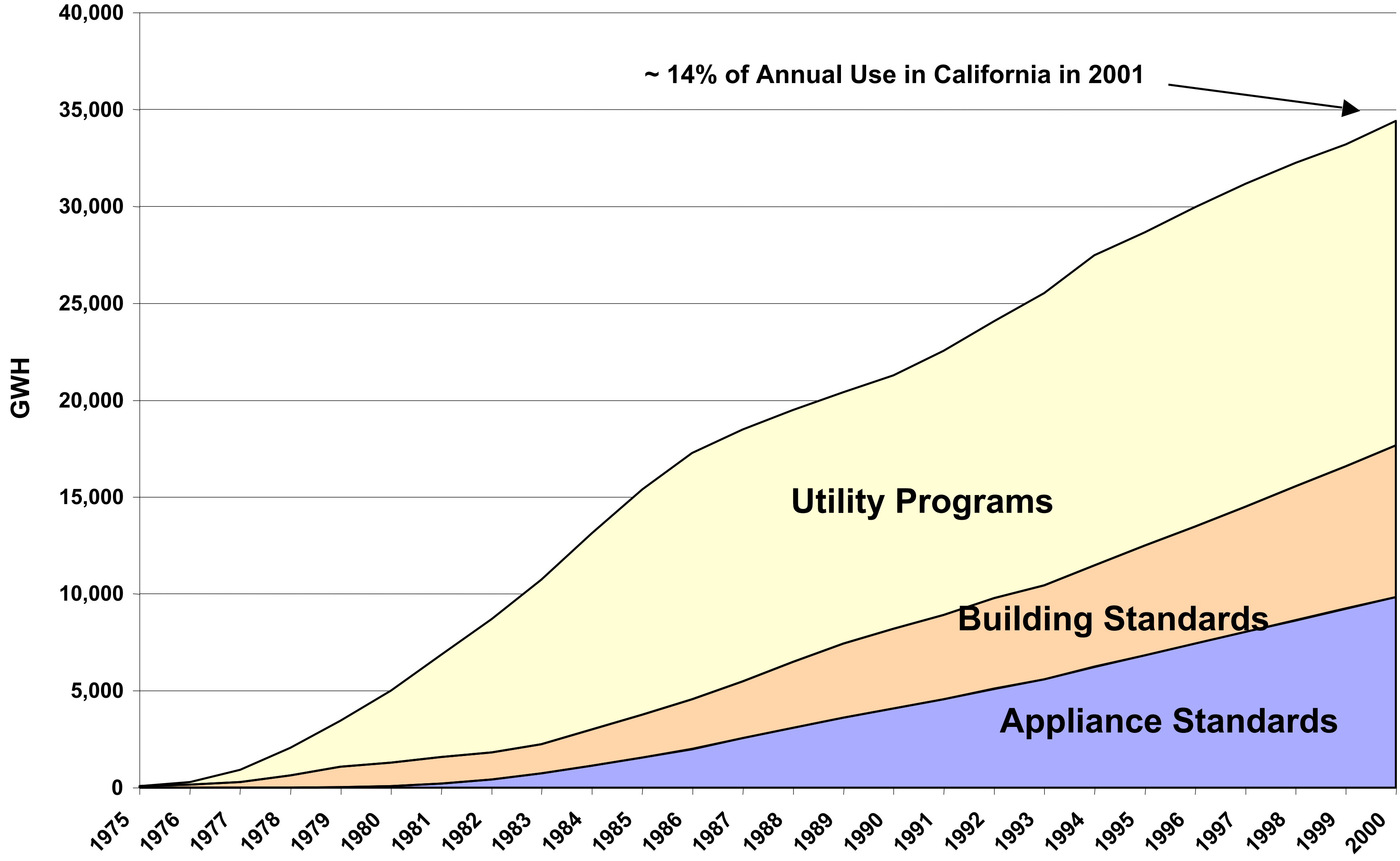


Impact of Standards on Efficiency of 3 Appliances



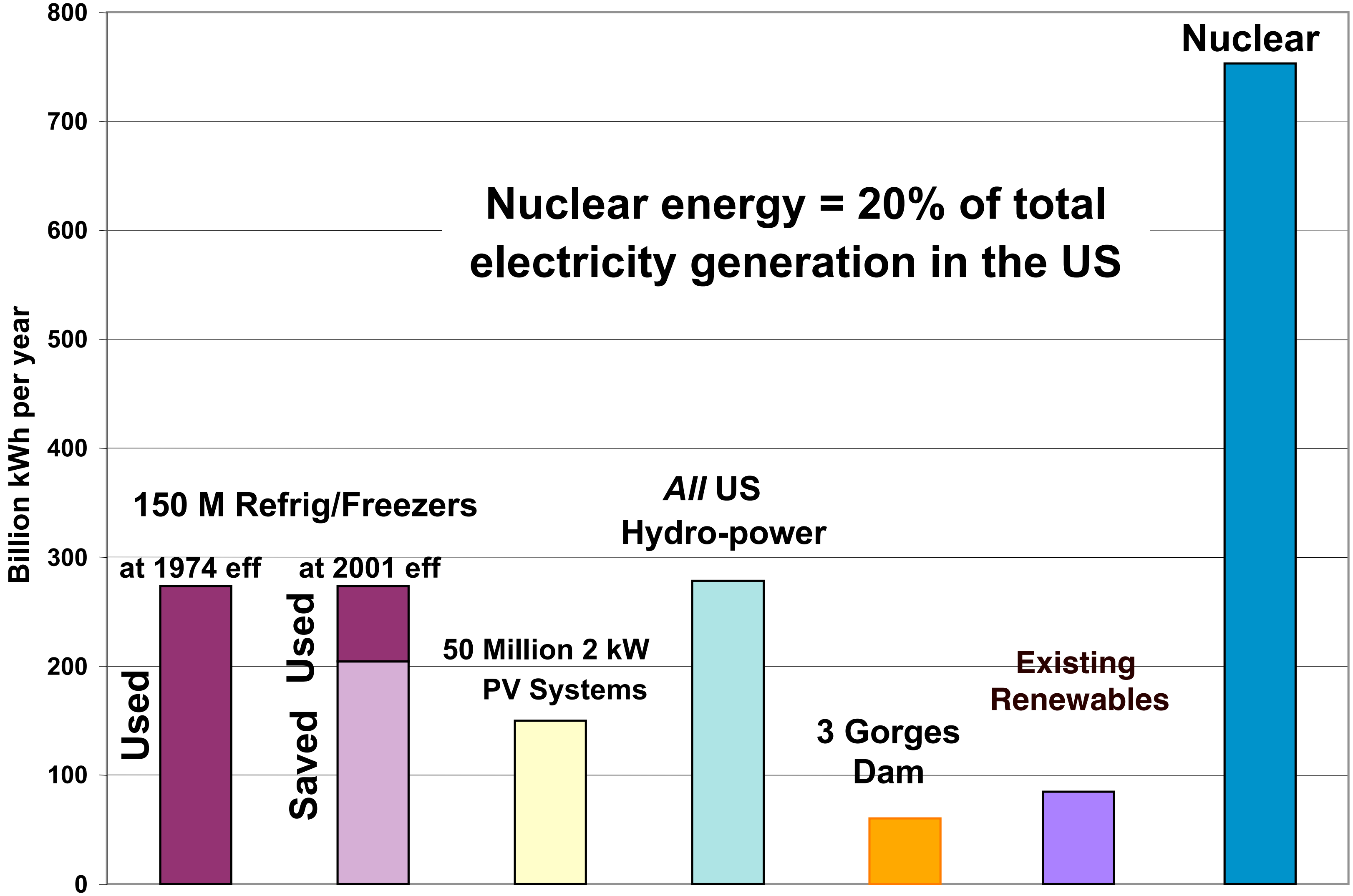
Source: S. Nadel, ACEEE, in ECEEE 2003
Summer Study, www.eceee.org

GWH Impacts from Programs Begun Prior to 2001



Source: Mike Messenger, CEC Staff, April 2003

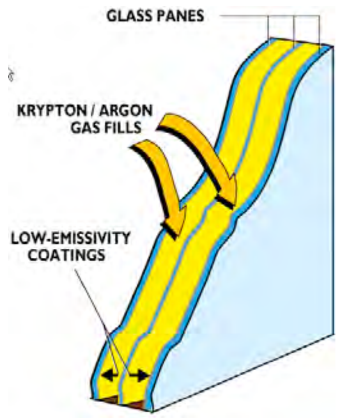
Electricity Use of Refrigerators and Freezers in the US compared to Generation from Nuclear, Hydro, Renewables, Three Gorges Dam and ANWR (Arctic National Wildlife Refuge)



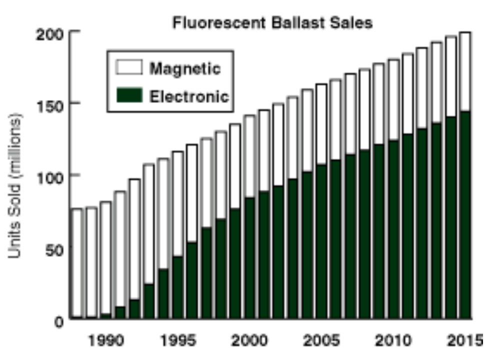
Efficiency

Energy for the Future

Arthur Rosenfeld, Figure 15

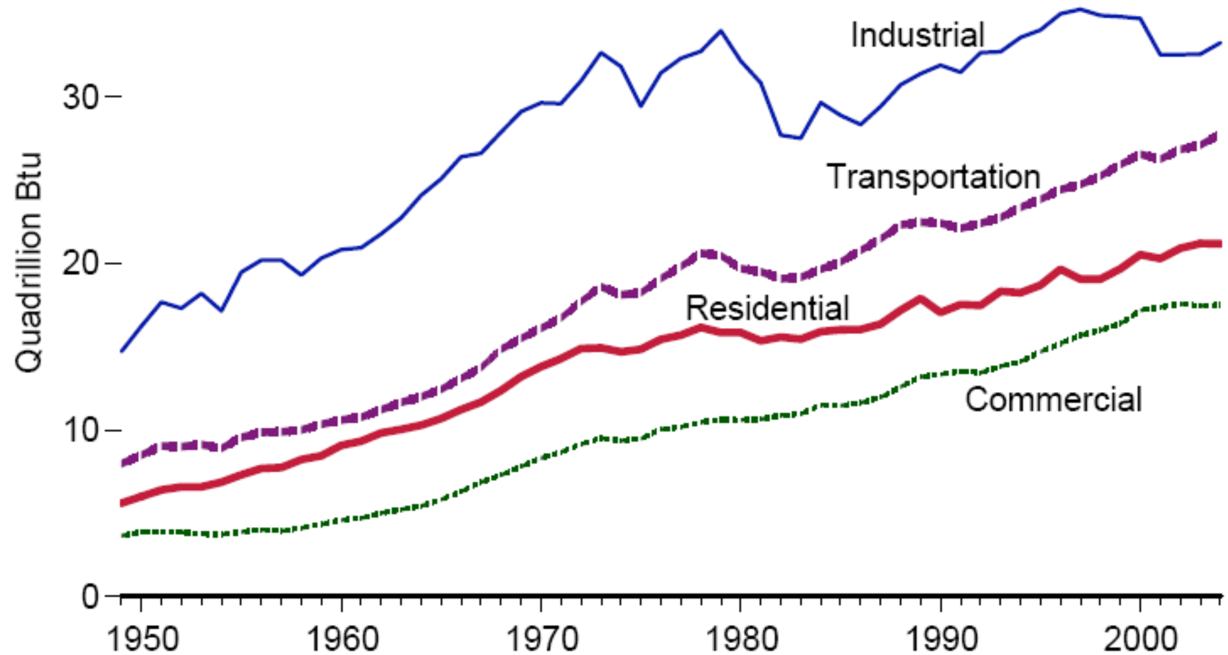


Cumulative U.S. energy savings for windows installed by 1995: $2.1 B

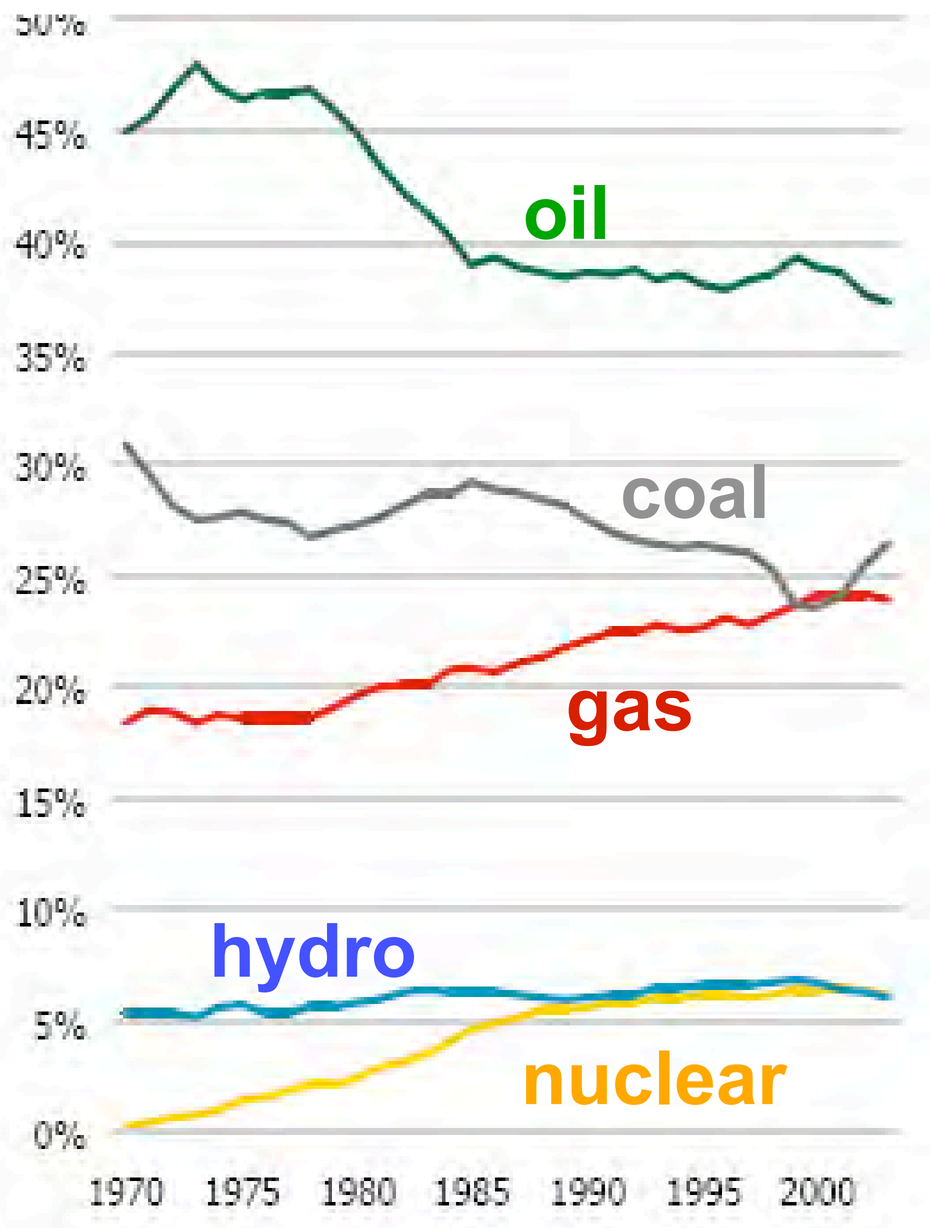


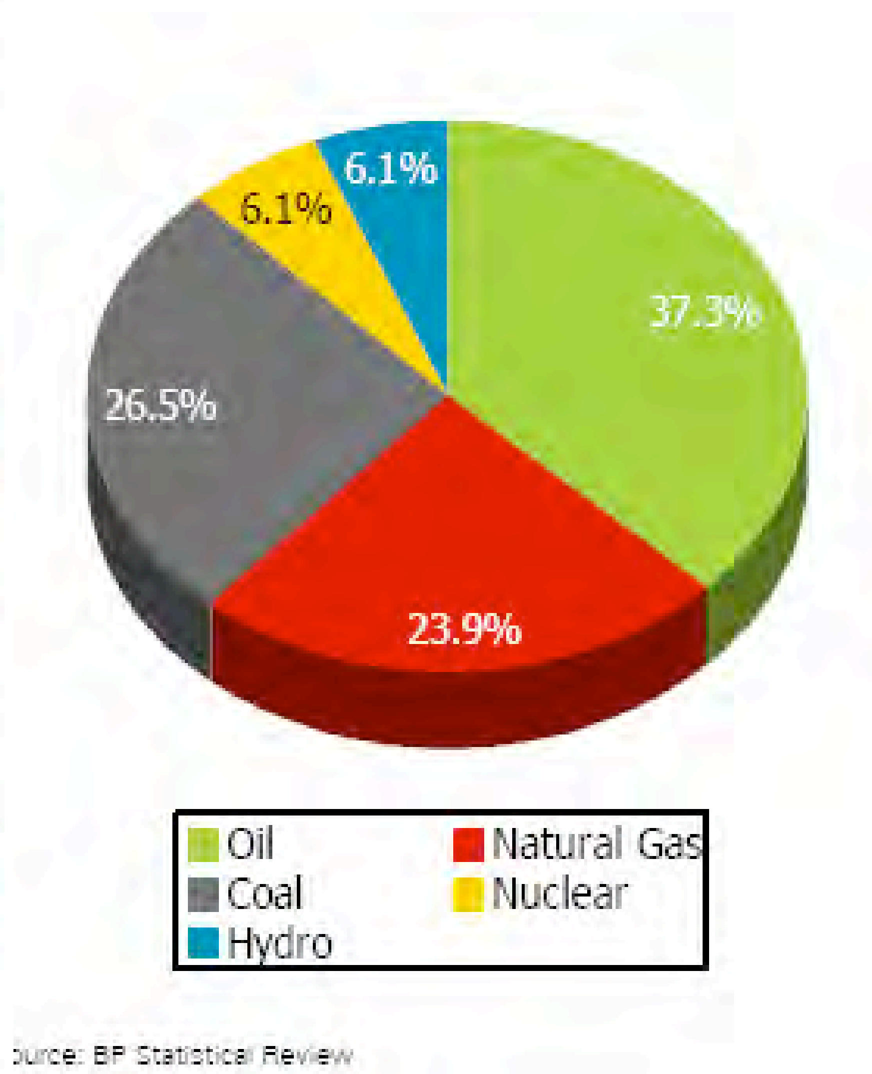
Cumulative US energy savings of electronic ballasts by 1995 = $1 B.

Total energy consumption at end-use sector 1949 – 2004



Energy sources (1970 – 2004)

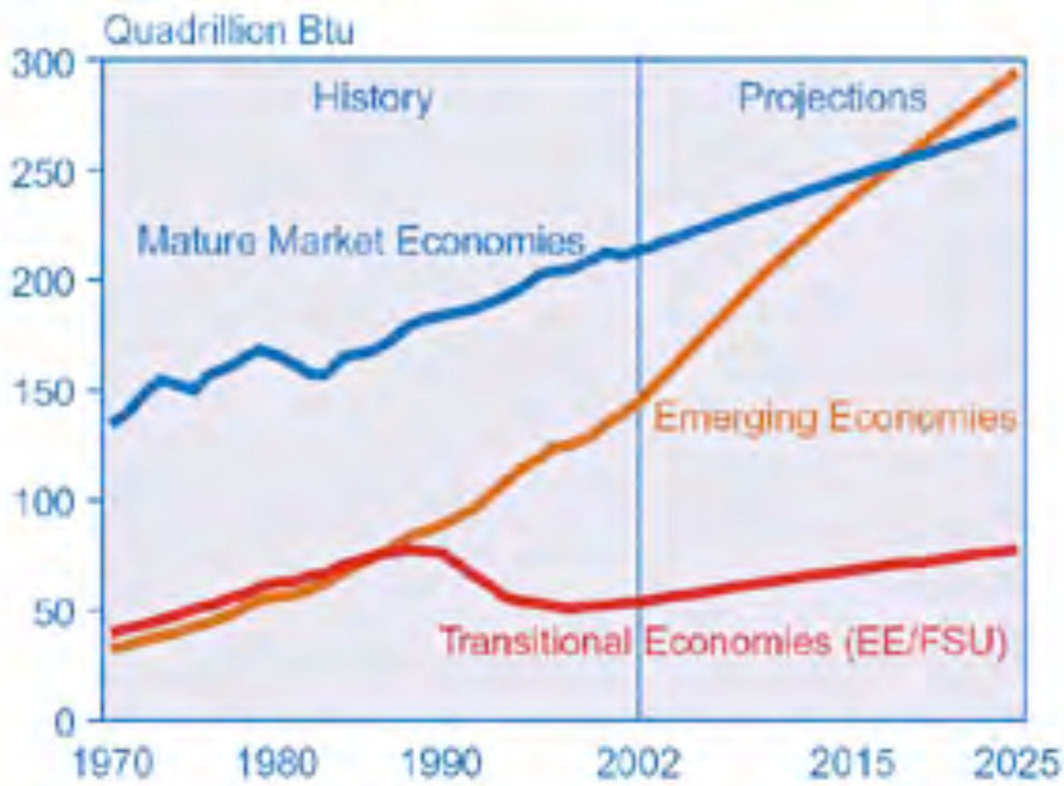




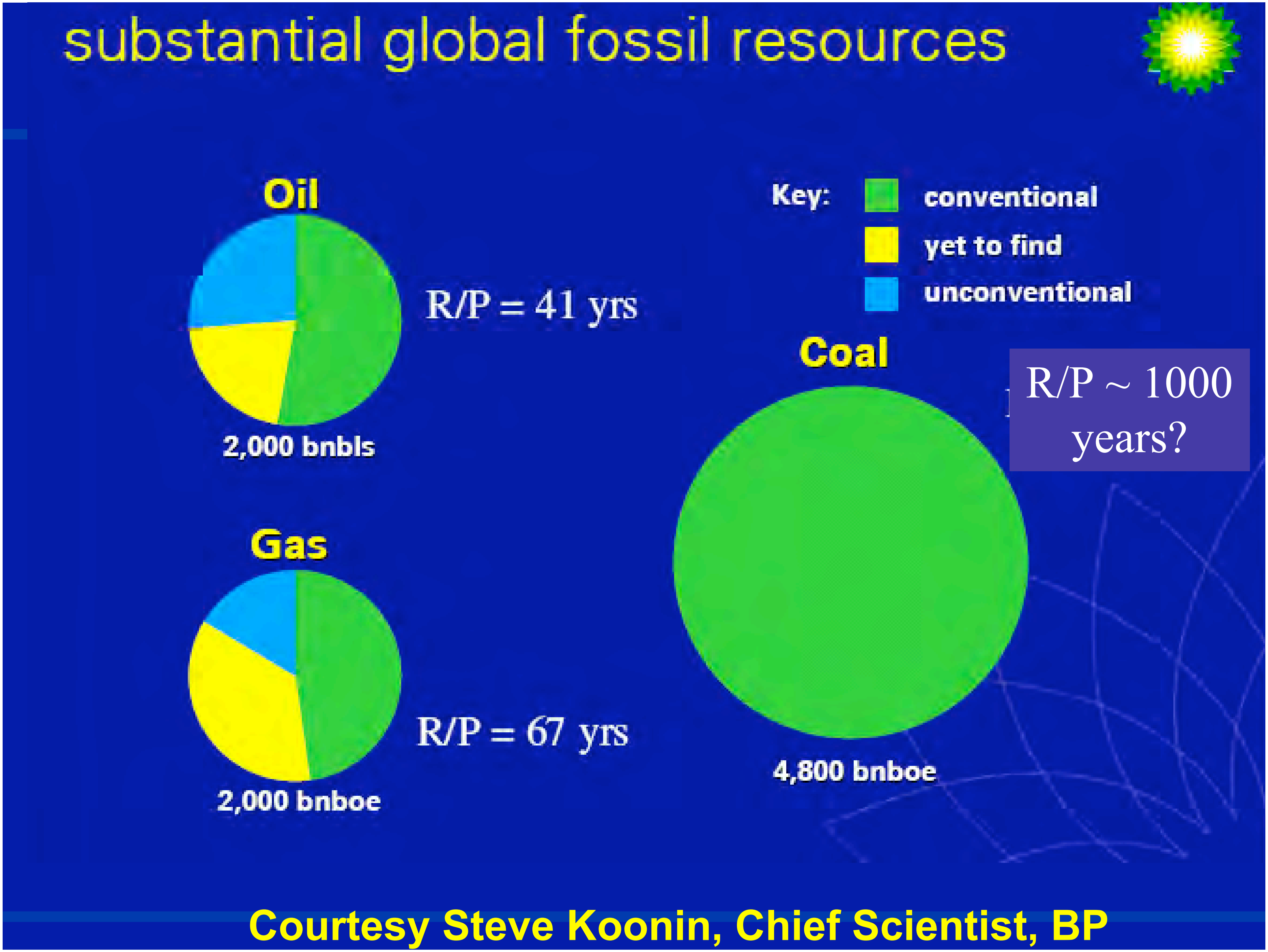
Potential supply-side solutions to the Energy Problem

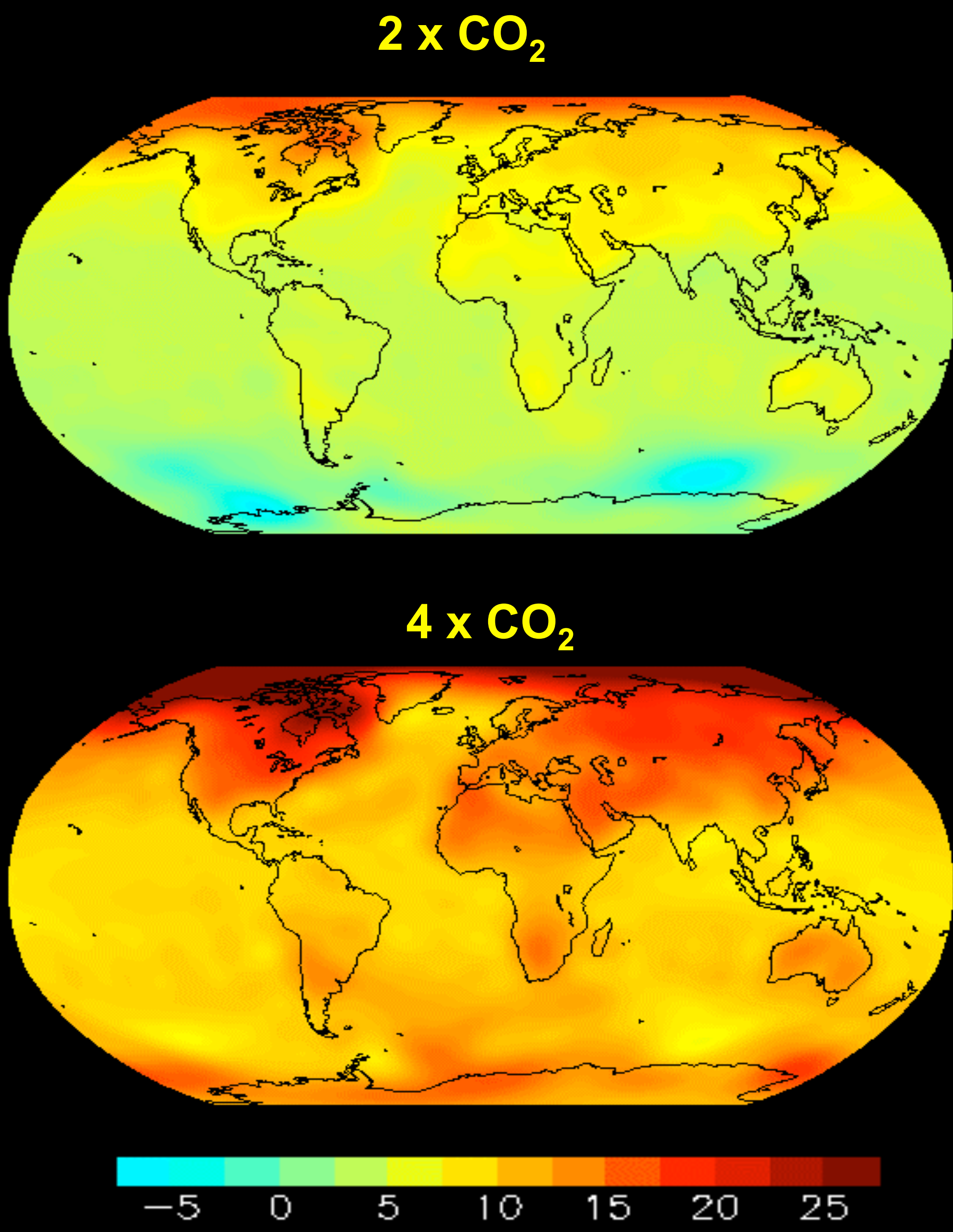
- Oil, gas, coal, tar sands, shale oil, …
- Fusion
- Fission
- Wind
- Solar photocells
- Bio-mass

Energy consumption by 2025 is expected to more than triple from 1970 levels.



When will we run out of fossil fuel energy?


substantial global fossil resources
Oil
R/P = 41 yrs
2,000 bnbls
Key:
conventional
yet to find
unconventional
Coal
R/P ~ 1000 years?
4,800 bnboe
Gas
R/P = 67 yrs
2,000 bnboe
Courtesy Steve Koonin, Chief Scientist, BP



Computer simulations by the Princeton Geophysical Fluid Dynamics Lab for CO2 increases above pre-industrial revolution levels:

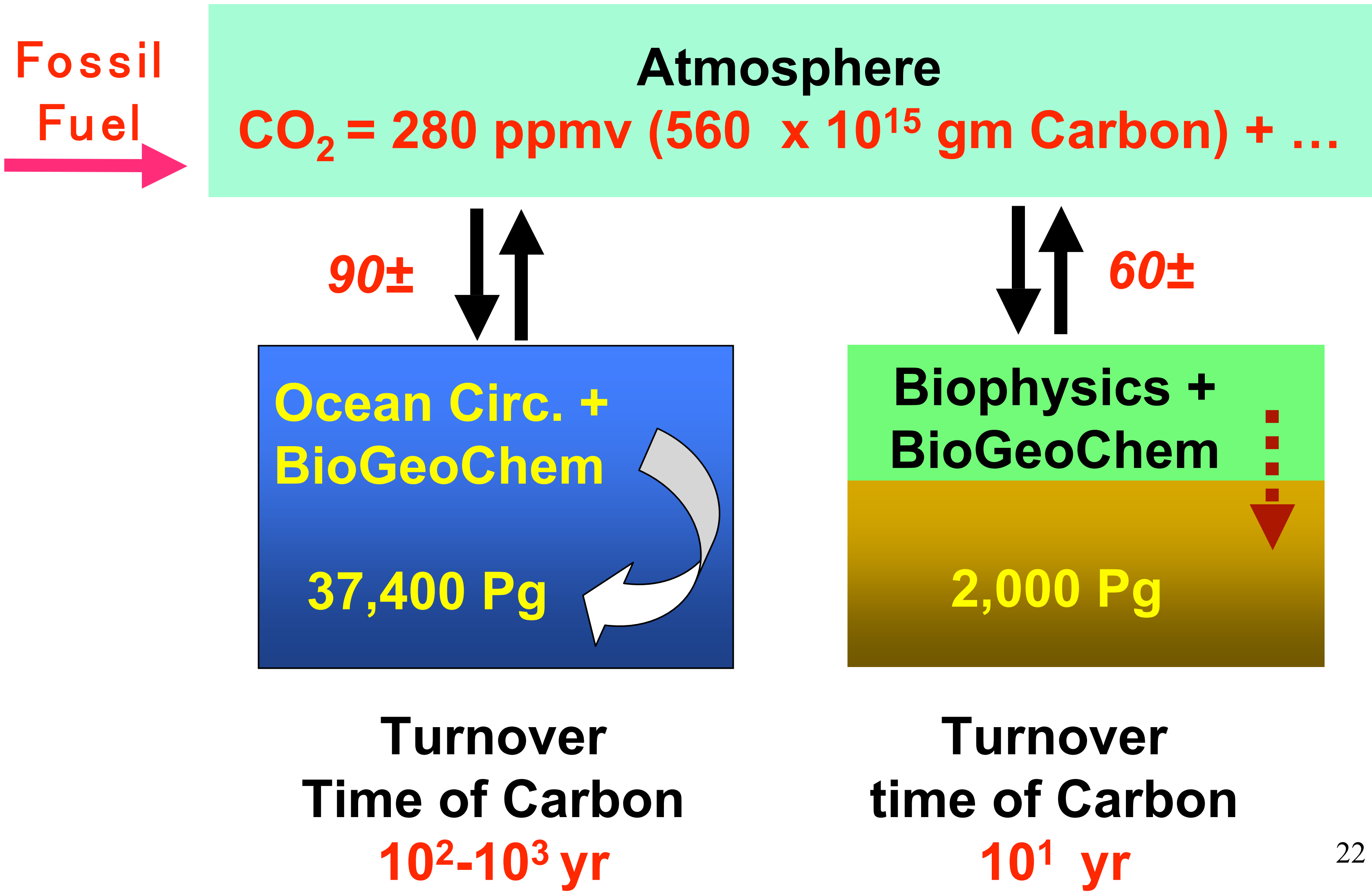
2x CO_2 : 3 – 5° C

4x CO_2 : 6 - 10° C

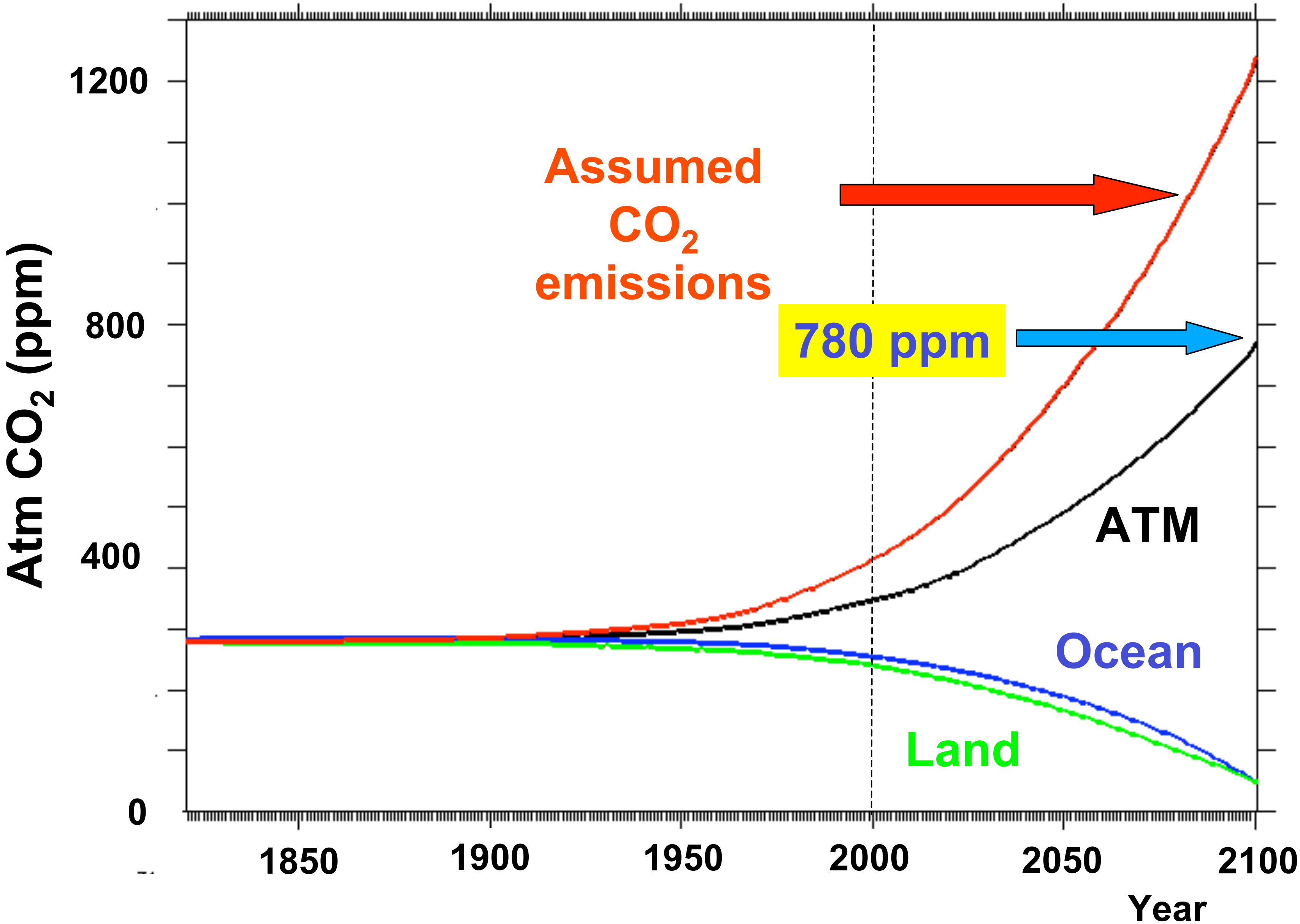
Pre-industrial:
~275 ppm

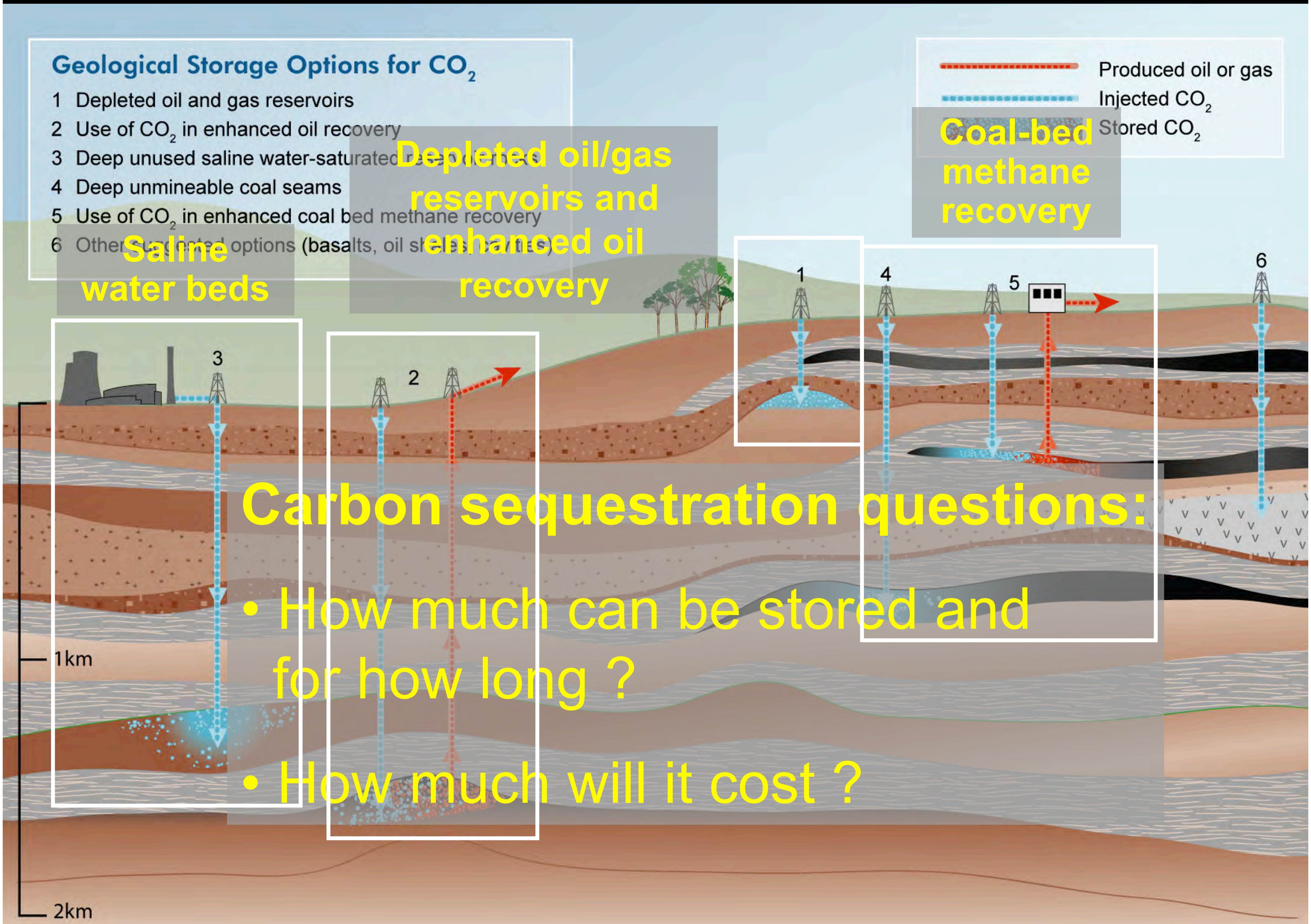
Today:
~380 ppm

New Climate Models include bio-geo-chemical feedbacks (Inez Fung, UCB and LBNL)



Fossil Fuel Simulation assuming A2 emission




Geological Storage Options for CO_2
1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil recovery
3 Deep unused saline water-saturated reservoirs
4 Deep unmineable coal seams
5 Use of CO_2 in enhanced coal bed methane recovery
6 Other suggested options (basalts, oil shales, cavities)
Produced oil or gas
Injected CO_2
Stored CO_2
Saline water beds
Depleted oil/gas reservoirs and enhanced oil recovery
Coal-bed methane recovery
1km
2km
Carbon sequestration questions:
• How much can be stored and for how long ?
• How much will it cost ?

Potential supply-side solutions to the Energy Problem

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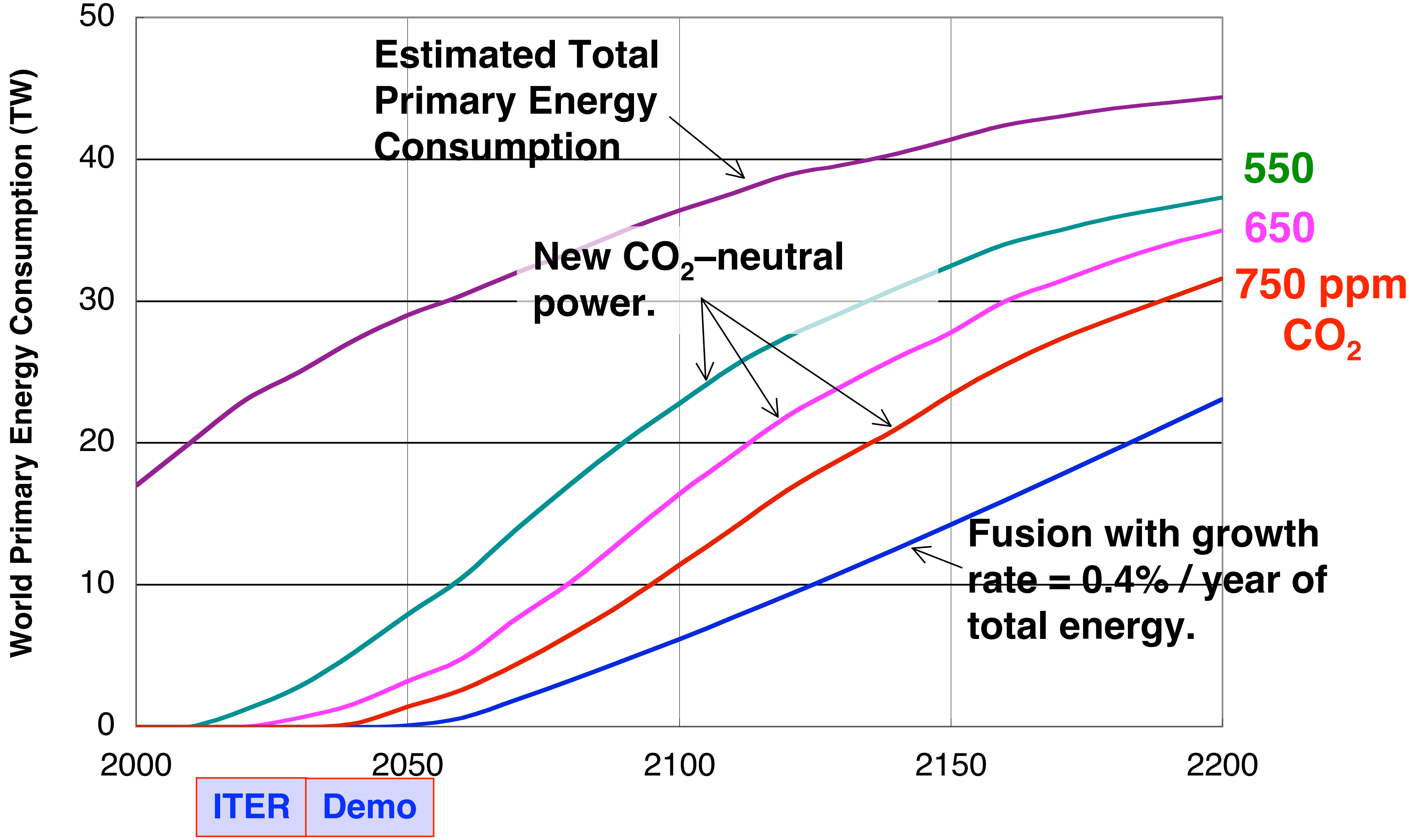
Fusion will not major contributor for most of the 21st century

Source: Rob Goldston, Princeton Plasma National Lab



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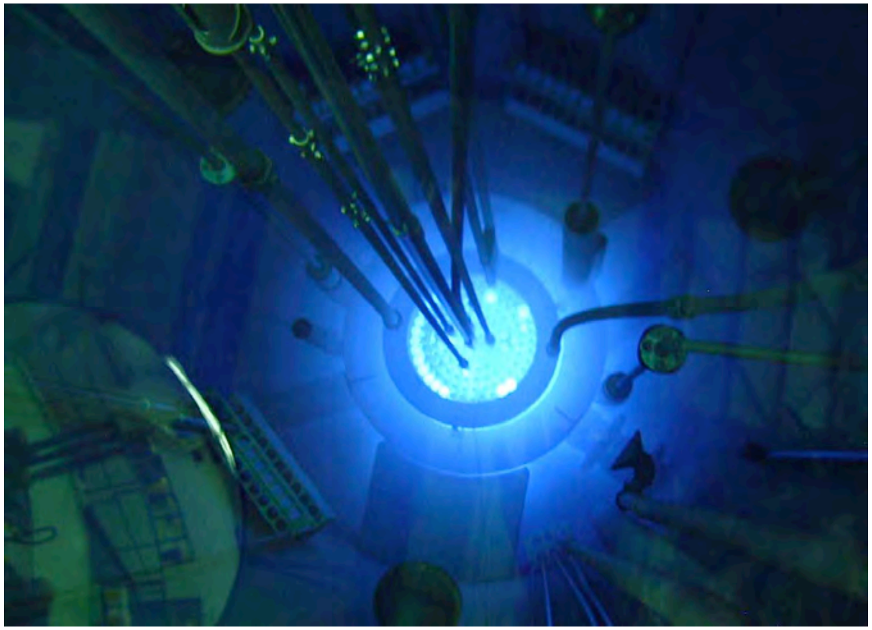
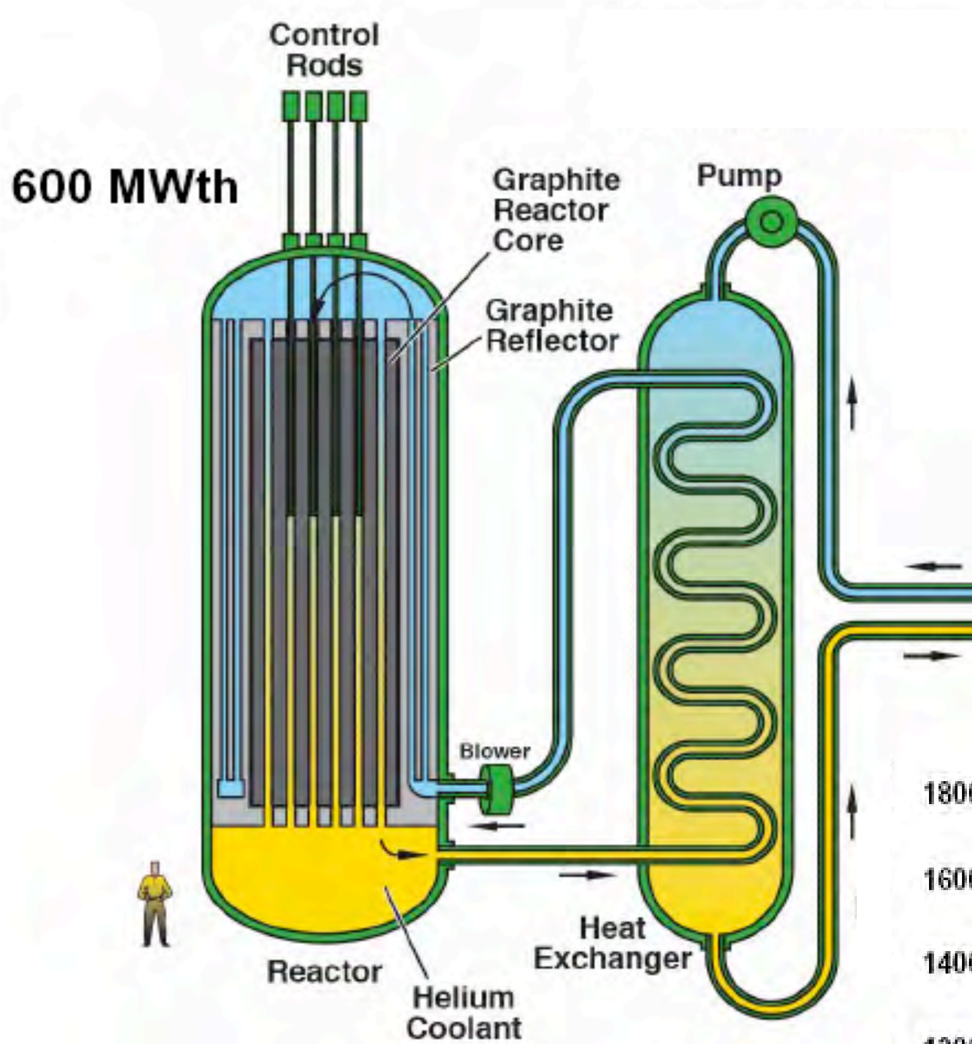
Nuclear Fission



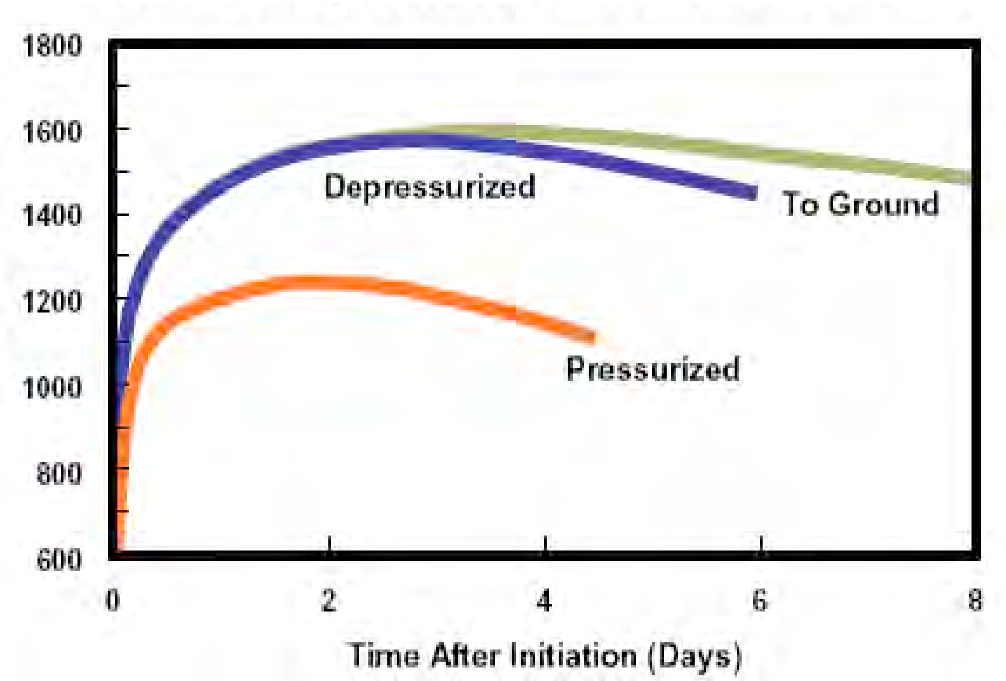
Waste and Nuclear Proliferation

3 TW = One new GW reactor every week for the next 50 years)

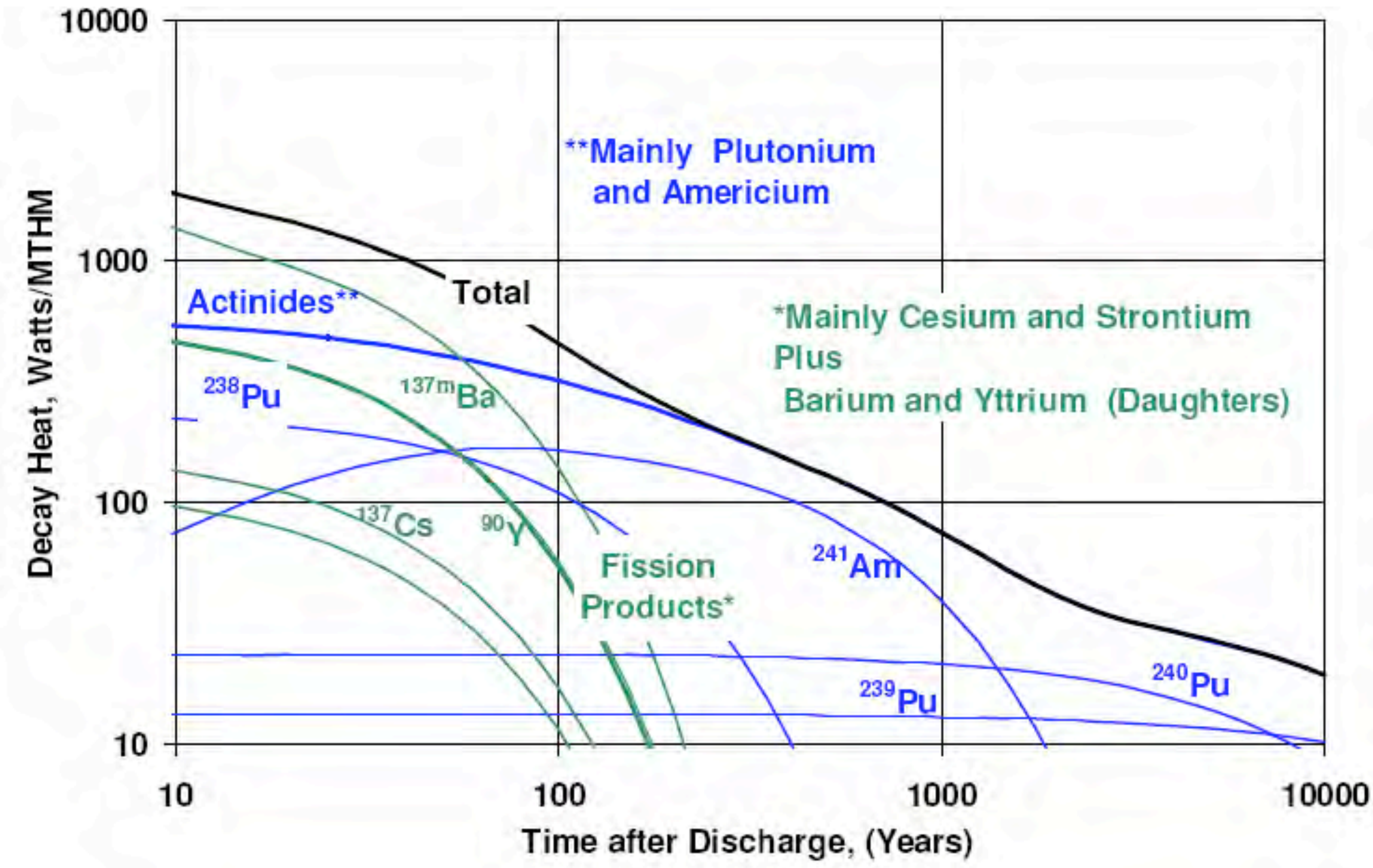


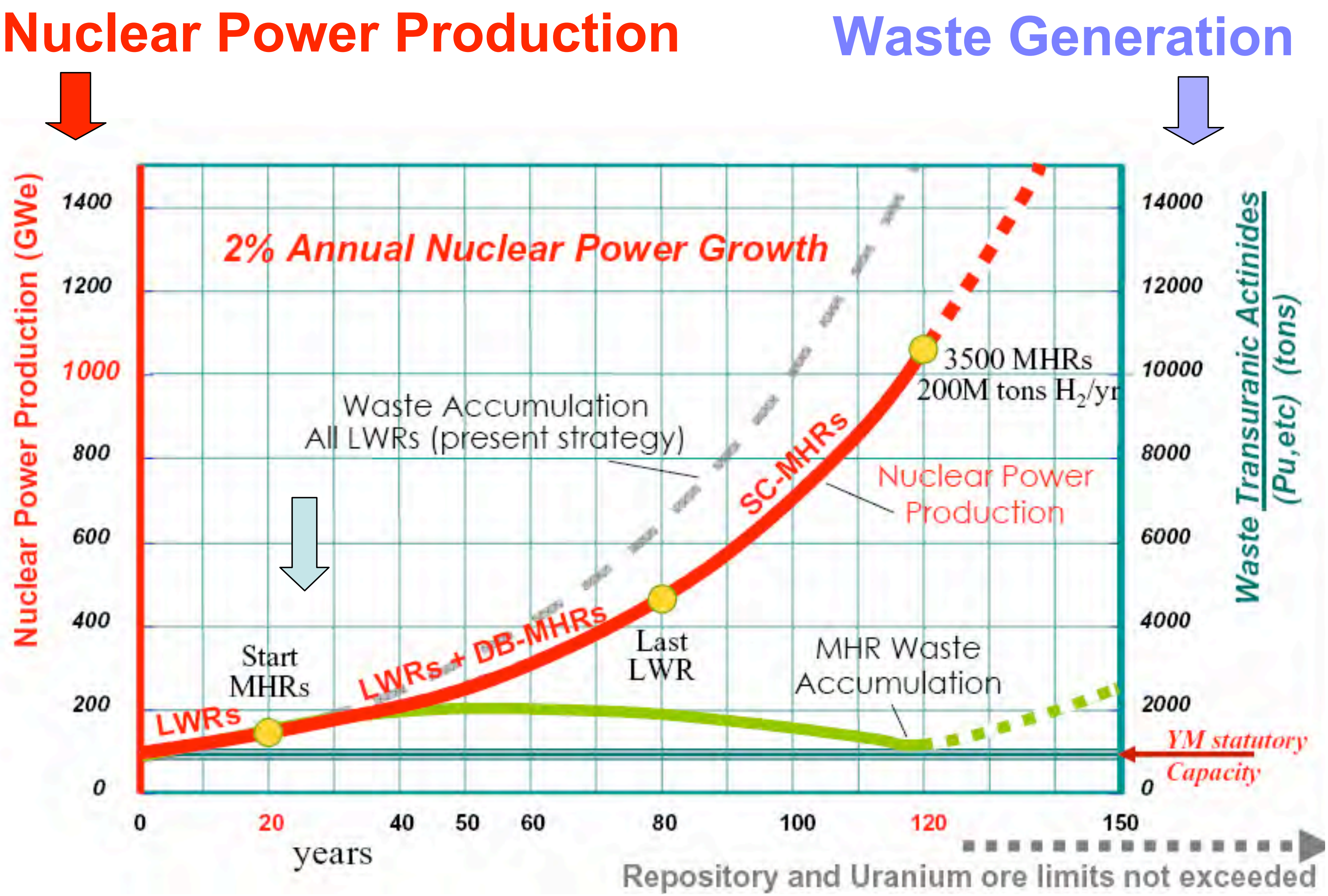
Graphite helium-cooled pebble bed reactor (General Atomics)

Max. fuel temperature



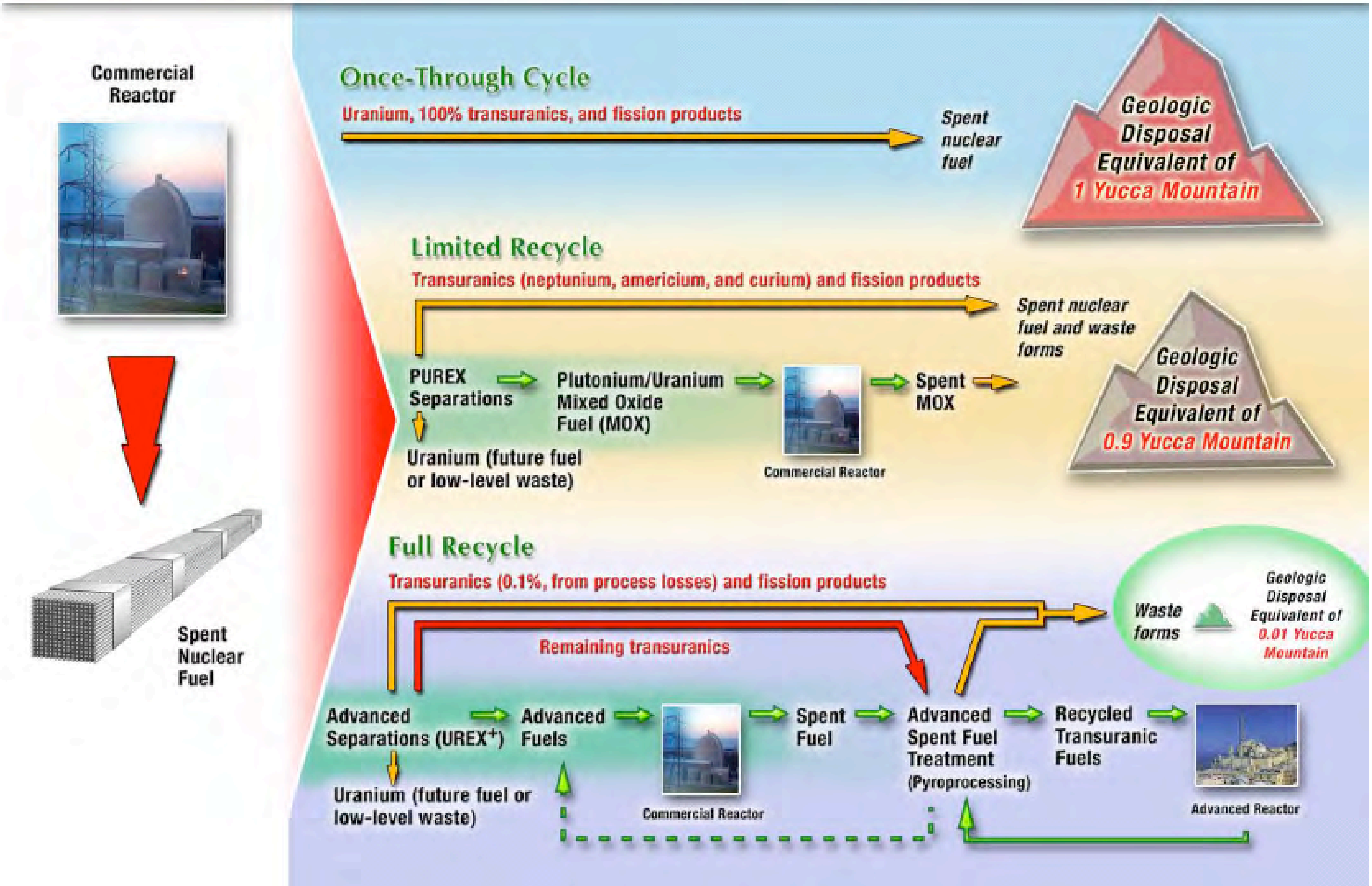
Heat generation is the limiting factor in long term storage





Assumes continued electricity growth and nuclear power remains at 20% of market share.

Spent Nuclear Fuel Management Options



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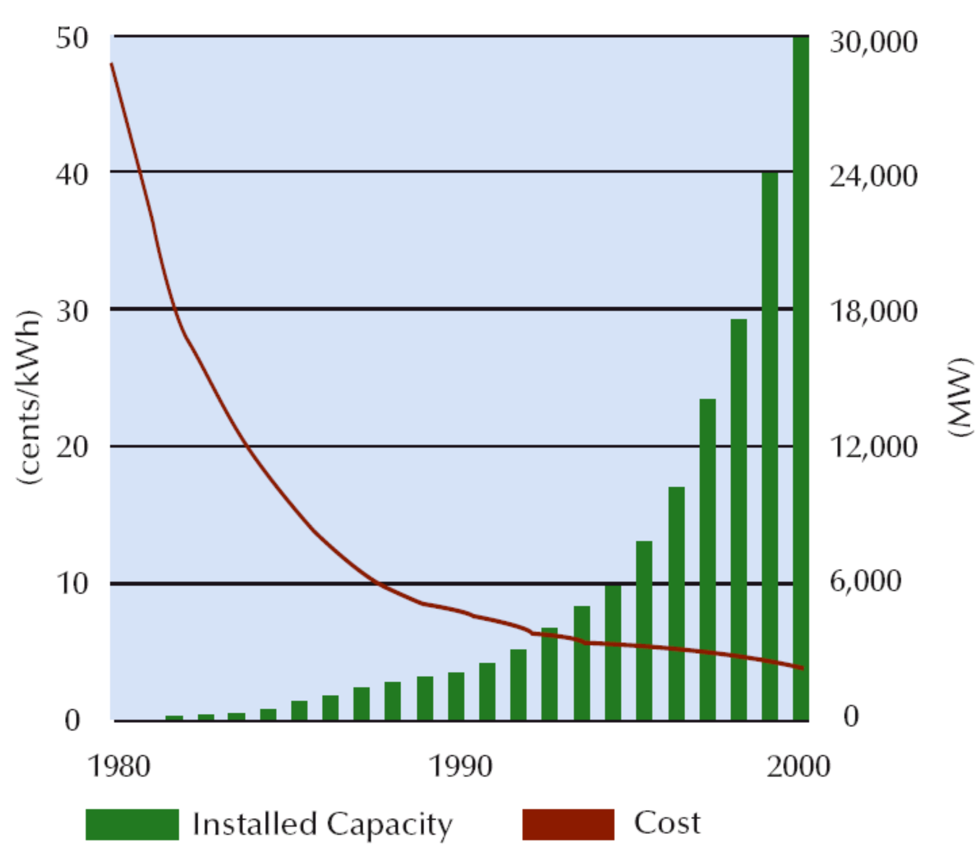
Tax incentives were essential to stimulate development of power generation from wind



Develop a new class of durable, high efficiency solar cells/collector systems at 1/10th the cost of current silicon solar arrays.

Direct band-gap, multiple layer solar cells combined with solar concentrators
(> 40% efficiencies now possible)

Distributed Junction Solar Cells
Organic materials for the creation of electron-hole pairs and charge separation, and a different material to collect the electrons.

Hierarchical Junction Solar Cells:
Materials which self-organize to form "hierarchical" junctions: e.g. the combination of organic dendrimers and inorganic branched nanocrystals.

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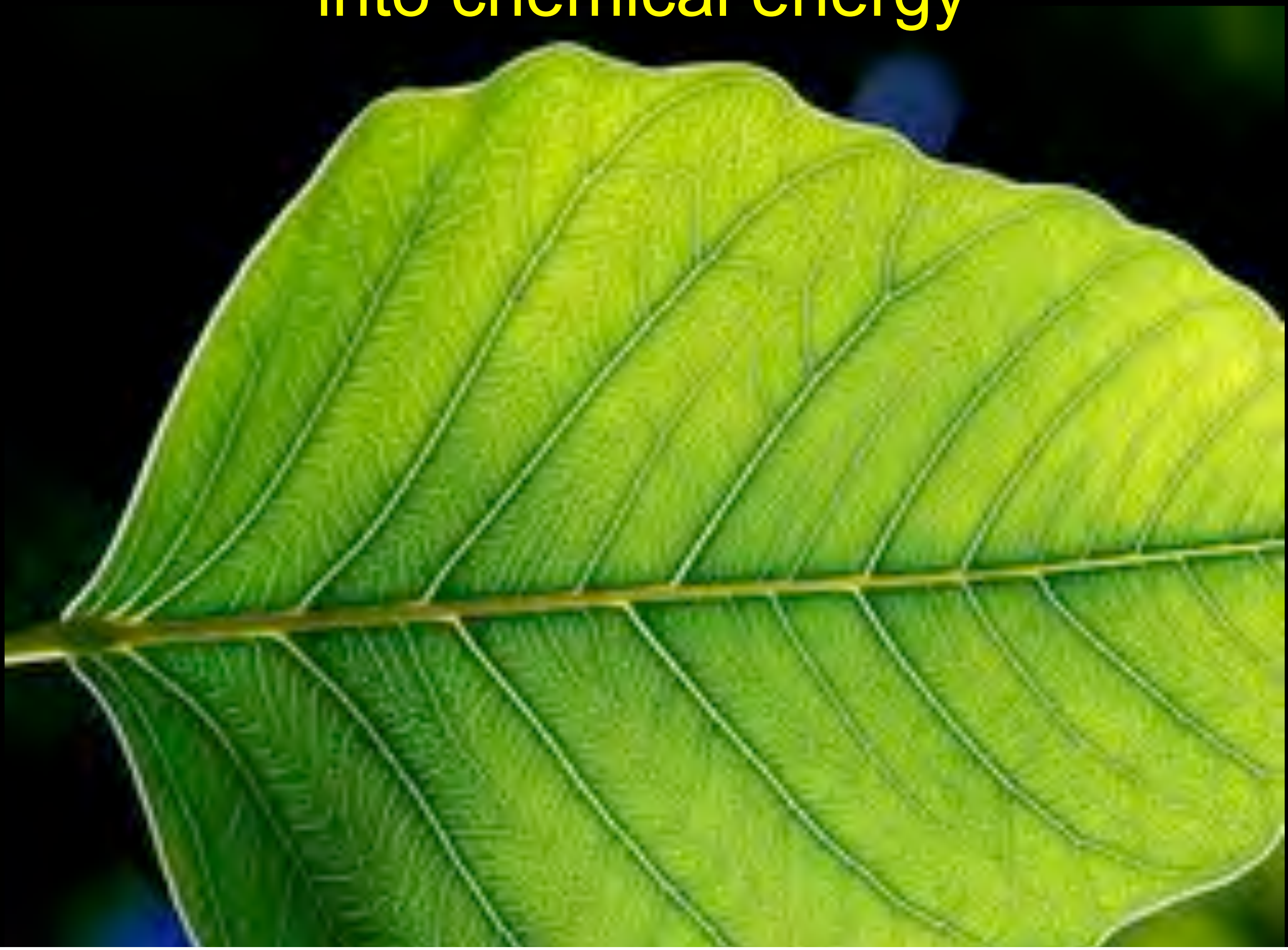
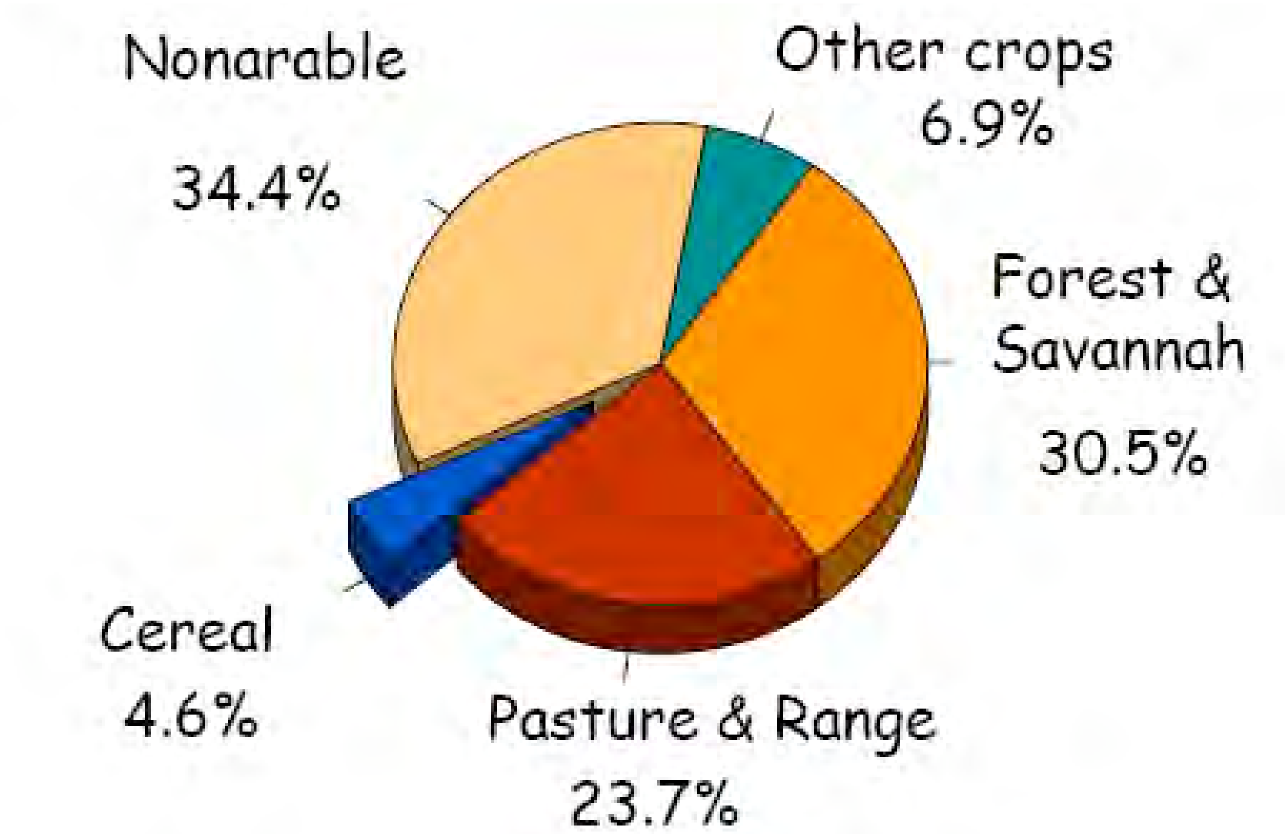
Photosynthesis: Nature has found a way to convert sunlight, CO_2, water and nutrients into chemical energy

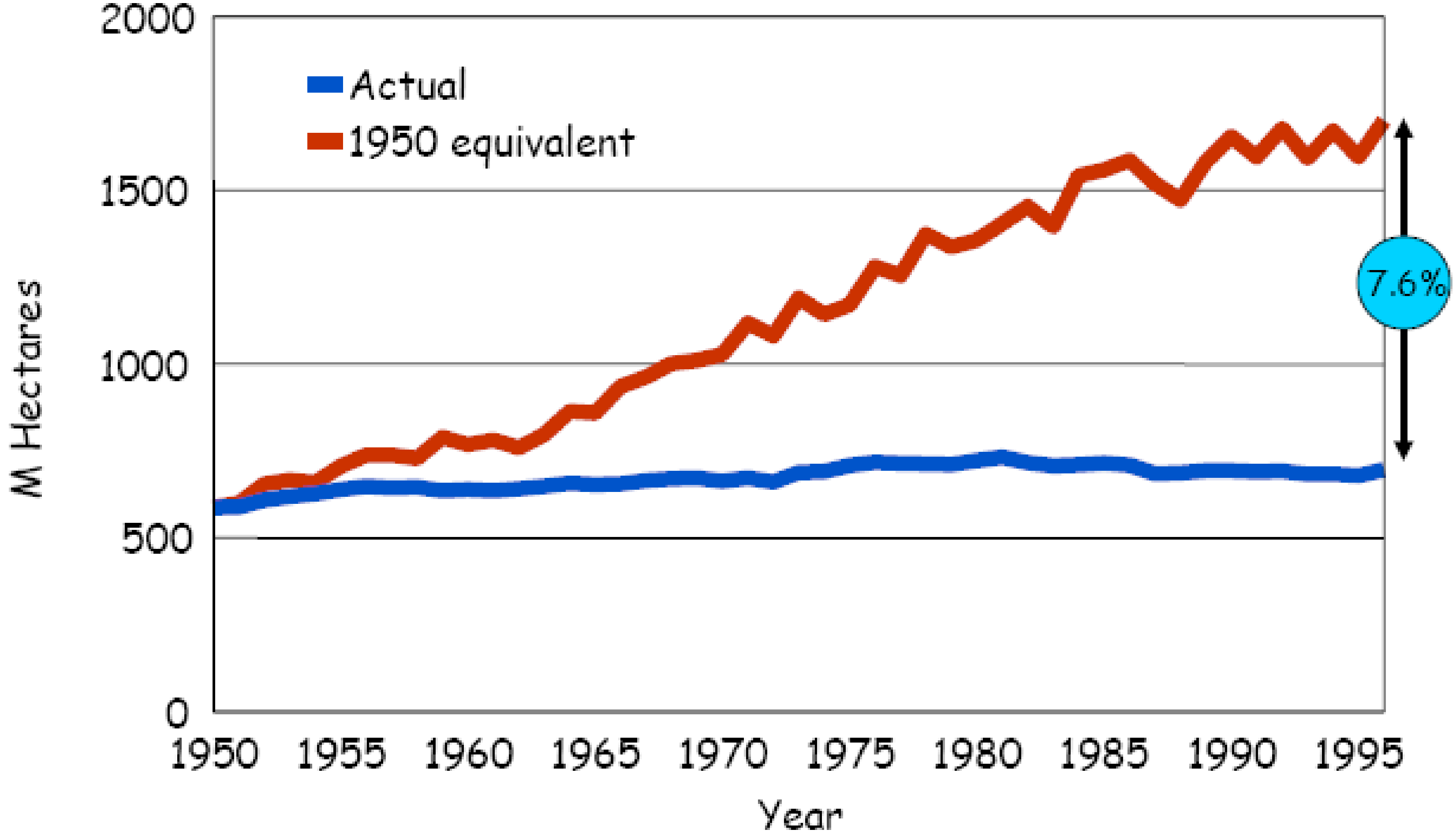


~13 B ha of land in the Earth

- 1.5 B ha for crops
- 3.5 B ha for pastureland
- 0.5 B ha are "built up"
- 7.5 B ha are forest land or "other"



Hectares of Grain With and Without Yield Improvements



Data from Worldwatch database 1996, 1997

Land best suited for biomass generation (Latin America, Sub-Saharan Africa) is the least utilized

Table1 Land distribution

	Suitable for rain fed crops Billion ha	Arable land in use, 1997-1999, %
Latin America and Caribbean	1.07	19
Sub-Saharan Africa	1.03	22
Industrial Countries	0.87	44
Transition Countries	0.50	53
Asia	0.59	75
Near East and North Africa	0.10	86

Potential arable land suitable for rain-fed crops:
1.5 Billion ha $\Rightarrow$ 14 Billion ha

The majority of a plant is structural material

Cellulose	40-60% Percent Dry Weight
Hemicellulose	20-40%
Lignin	10-25%

Sunlight
CO_2, H_2O,
Nutrients

→ Biomass → Chemical energy

Self-fertilizing, drought and pest resistant

Improved conversion of cellulose into chemical fuel

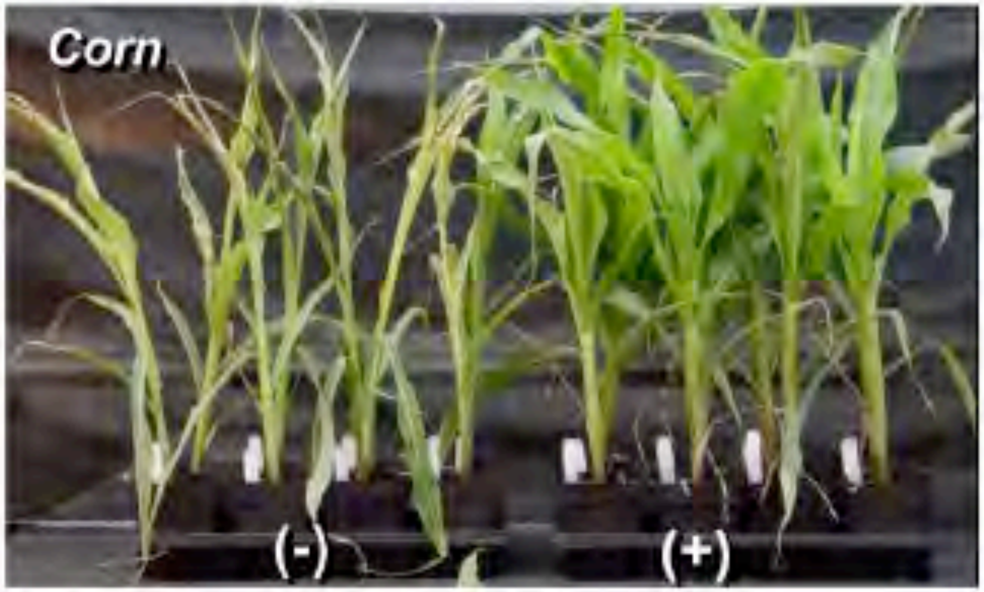
Replace NH_3 fertilizer with Biological N fixation

- Engineer major crop plants to contain the nitrogen fixation genes

OR

- Engineer major crop plants to accept nitrogen fixing bacteria in root nodules

Progress in engineering crops plants for drought resistance



From Christopher Somerville, IAC workshop, 2006

> 1% conversion efficiency may be feasible.

1 B ha (< 10% of potential non-irrigated crop land capability) might supply >100 Bn barrels of oil.

Current usage: 28 Bn barrels
2025 projection: 43 Bn barrels

- Miscanthus**:** 17.5 dry tons/acre
- 200 gallons of ethanol / dry ton may be possible.
- 200 M out of 450 M acres $\Rightarrow$ ~17 Bnb oil
- US transportation = 13 Bnb

Commercial ethanol production from cellulose

The biggest energy gains will come from improved fuel production from cellulose/lignin

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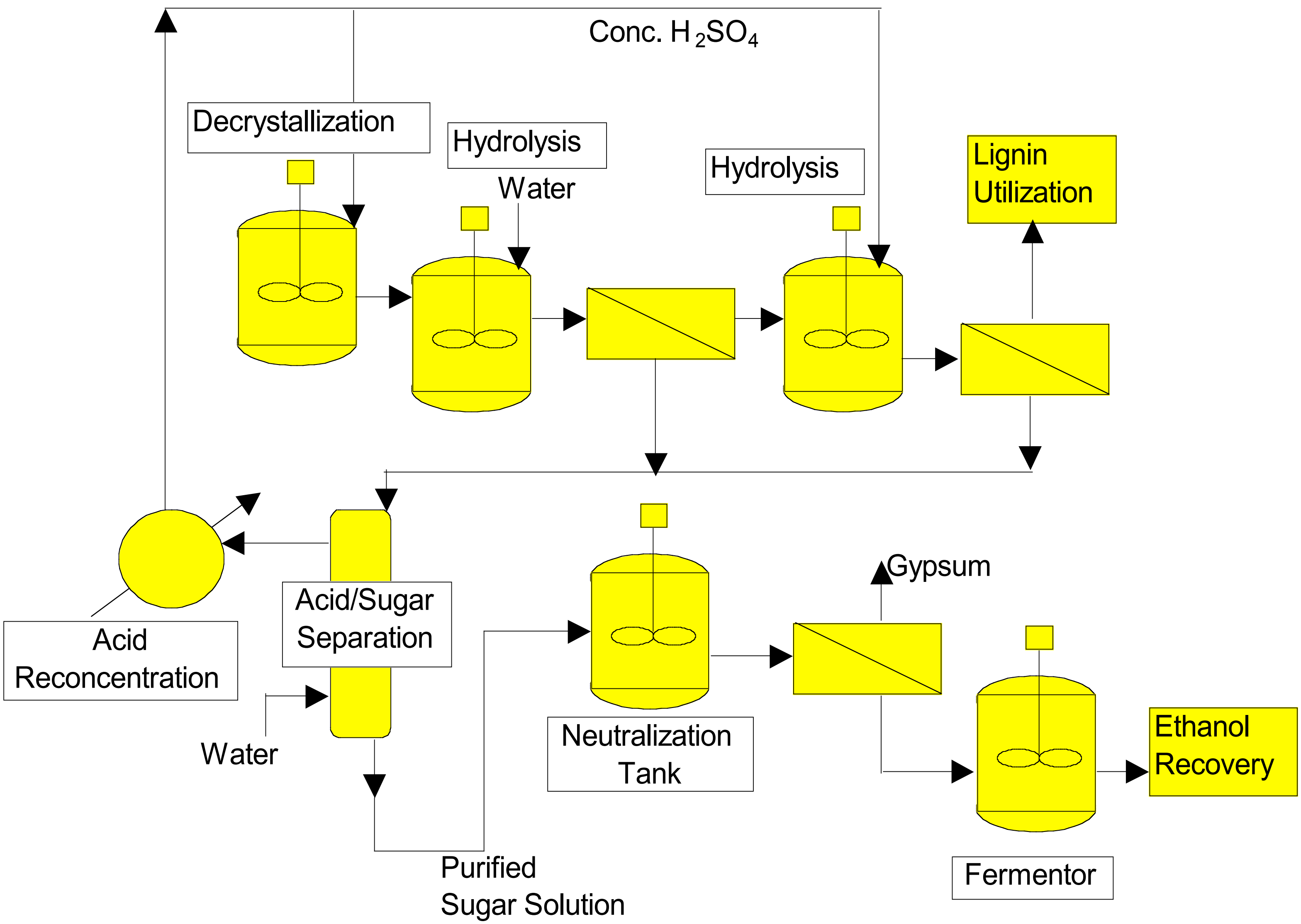
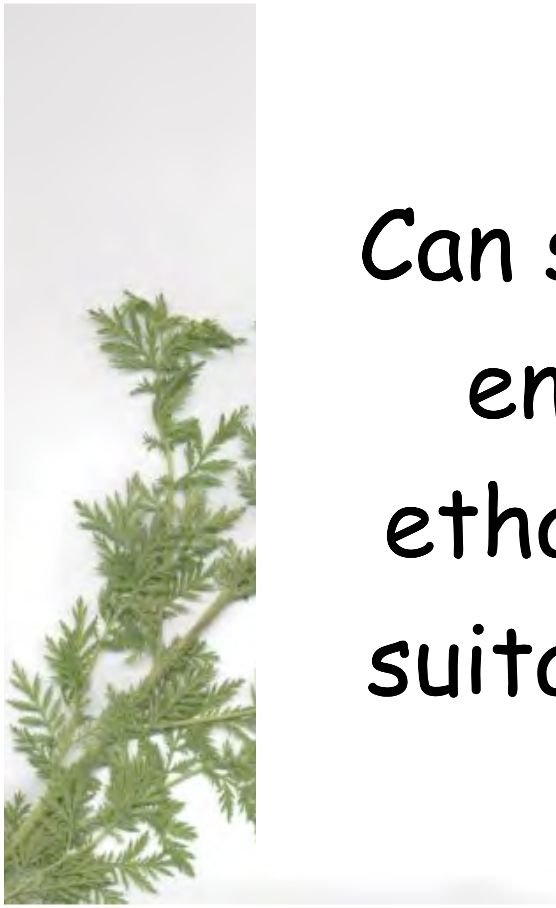
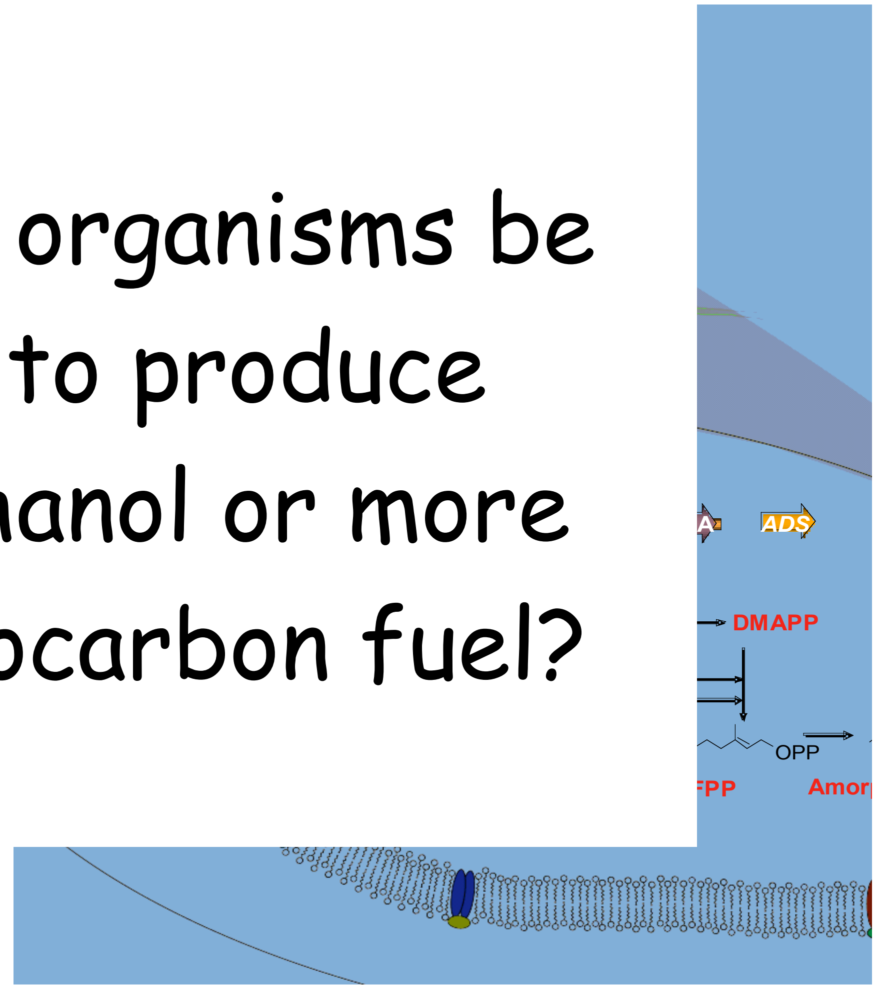


Synthetic Biology:

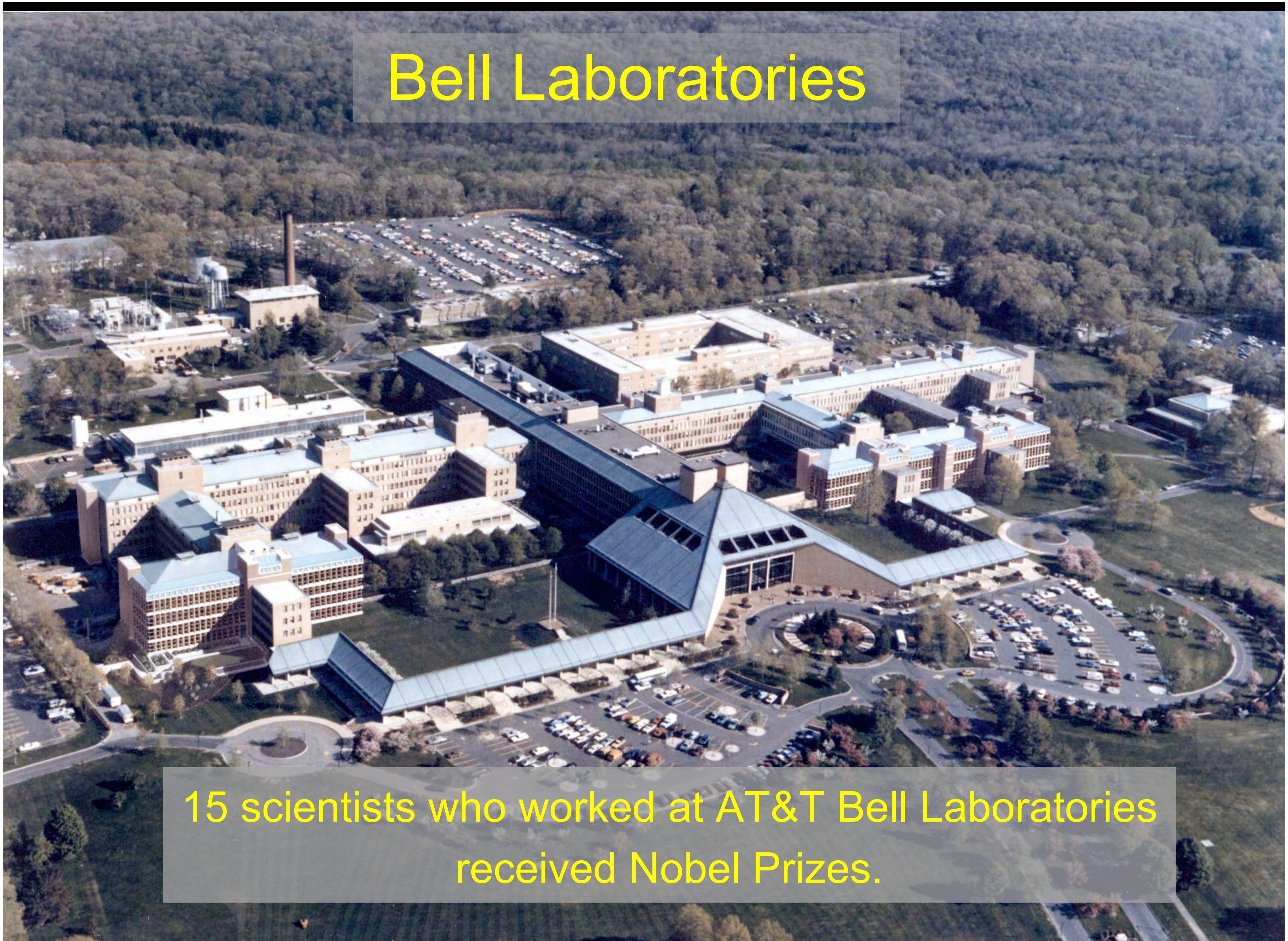
Production of artemisinin in bacteria Jay Keasling



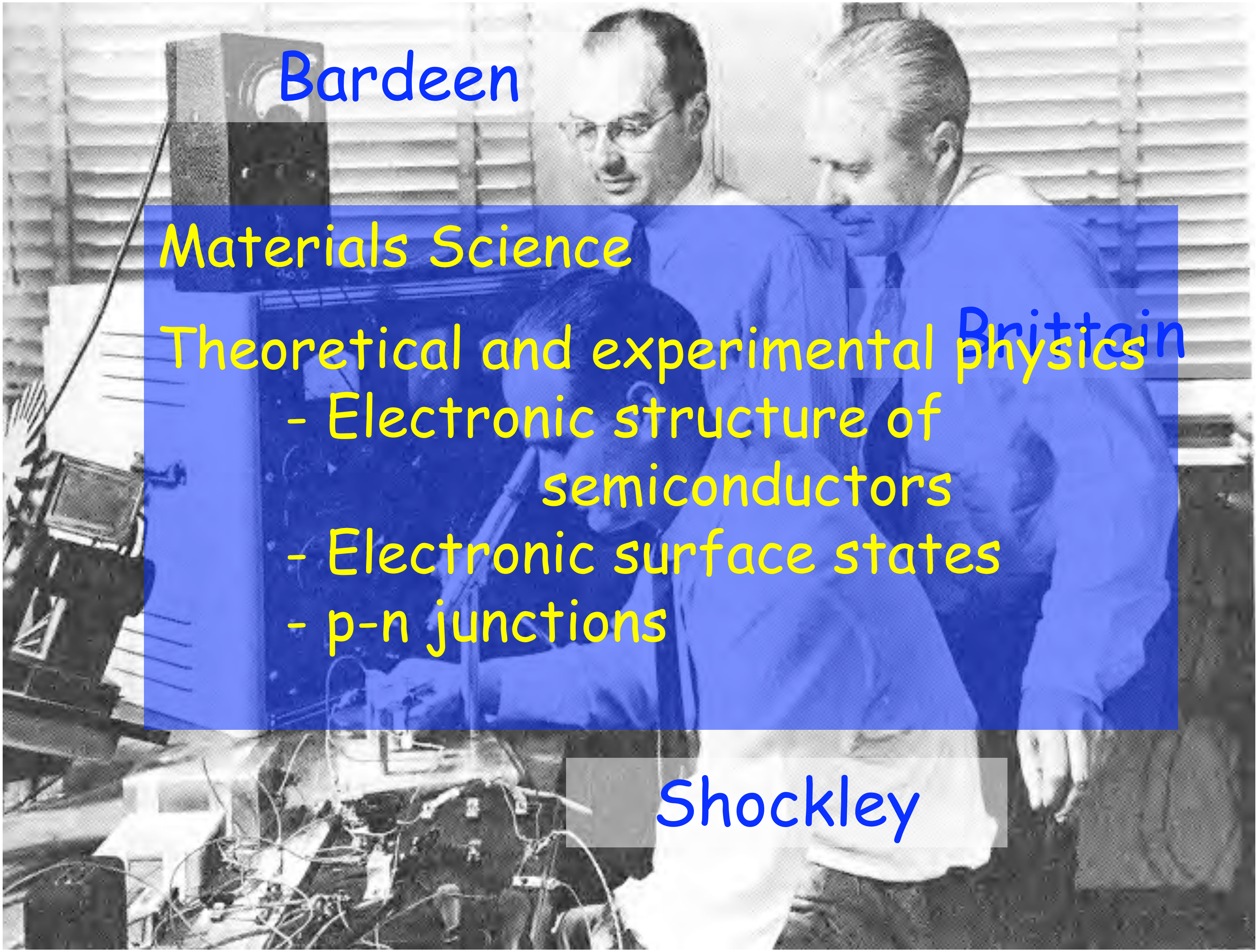
Can synthetic organisms be engineered to produce ethanol, methanol or more suitable hydrocarbon fuel?



Bell Laboratories



15 scientists who worked at AT&T Bell Laboratories received Nobel Prizes.


Bardeen
Materials Science
Brittain
Theoretical and experimental physics
- Electronic structure of semiconductors
- Electronic surface states
- p-n junctions
Shockley

Lawrence Berkeley National Laboratory

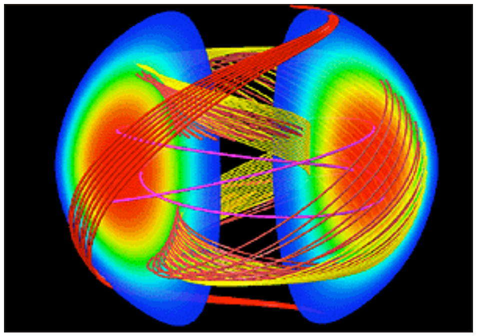
3,800 employees, ~$520 M / year budget

10 Nobel Prize winners were/are employees of LBNL, and at least one more "in the pipeline"

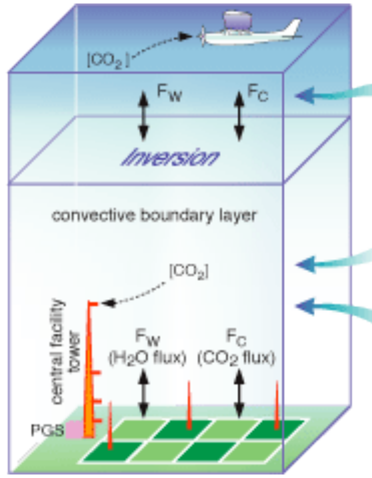
Today:

59 employees in the National Academy of Sciences,
18 in the National Academy of Engineering,
2 in the Institute of Medicine,
7 MacArthur Fellows...

Lawrence Berkeley Lab Energy Work

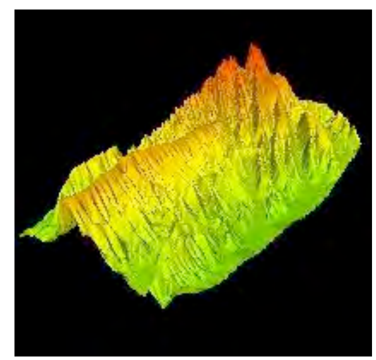


Fusion

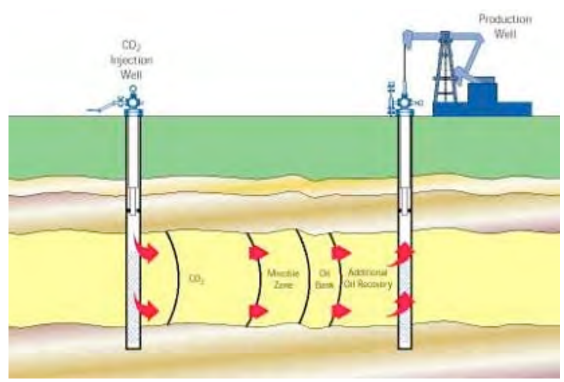


Carbon sequestration

geothermal



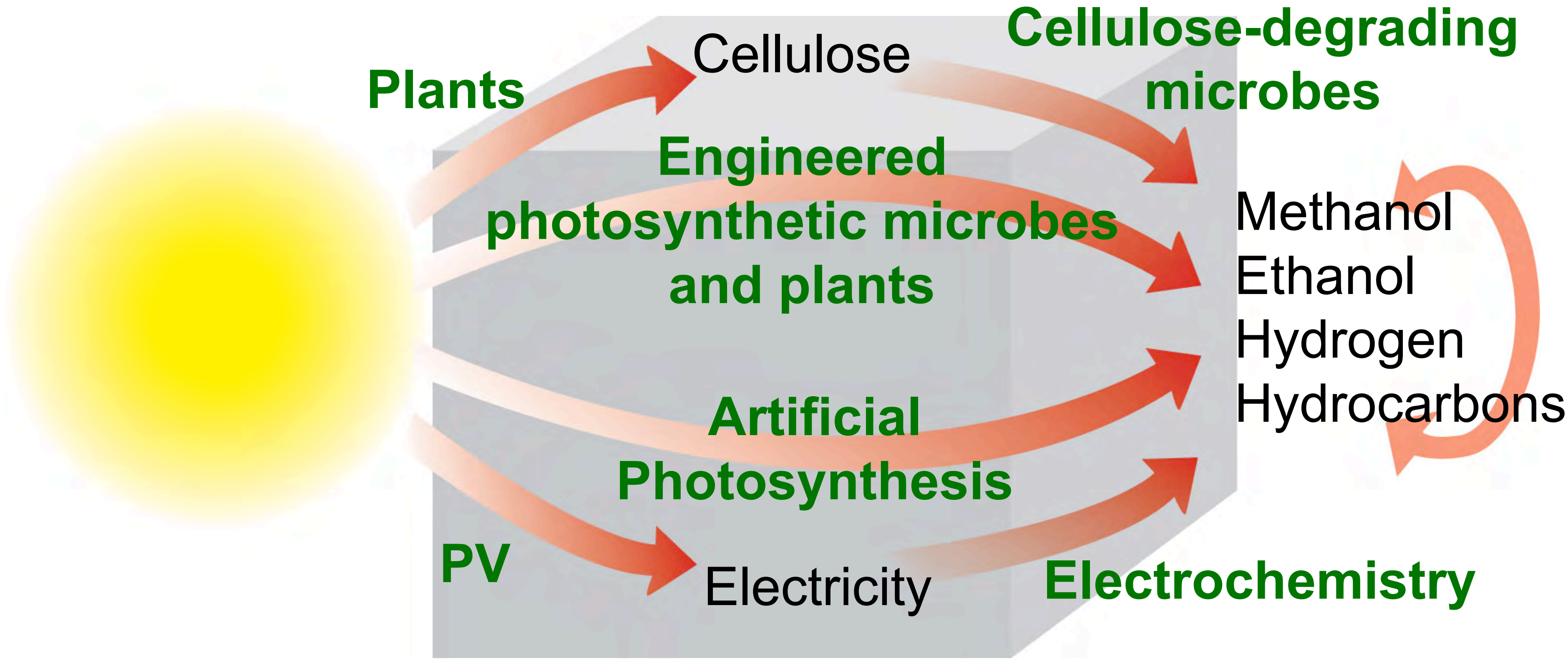
Energy Efficiency



Fossil recovery

Computation and Modeling

Helios


Plants
Cellulose
Cellulose-degrading microbes
Engineered photosynthetic microbes and plants
Methanol
Ethanol
Hydrogen
Hydrocarbons
Artificial Photosynthesis
PV
Electricity
Electrochemistry

Helios Research Building